EFFECT OF QUANTITY OF MIXING WATERS ON STRENGTH OF PORTLAND CEMENT MORTARS

BY

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ARMOUR INSTITUTE OF TECHNOLOGY

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THE EFFECT OF QUANTITY OF MIXING WATER ON THE STRENGTH OF VARIOUS PORTLAND CEMENT MORTARS

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THE EFFECT OF QUANTITY OF MIXING WATER ON THE STRENGTH OF VARIOUS PORTLAND CEMENT MORTARS

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PREFACE

This work represents the results of an investigation by the writer relative to the effect of the amount of mixing water on the strength of various Portland cement mortars.

In the series of experiments outlined in the following pages, mortars of four different proportions were used; each mortar was made up with seven different percentages of water, and specimens of the same age and consistency weretested for three different ages. An outline of the test specimens is given in Fig. I, page II.

The investigation required the making of 840 test specimens consisting of:

84 cylinders, 3" x 6".

336 cylinders, 2" x 4".

420 standard tension briquettes.

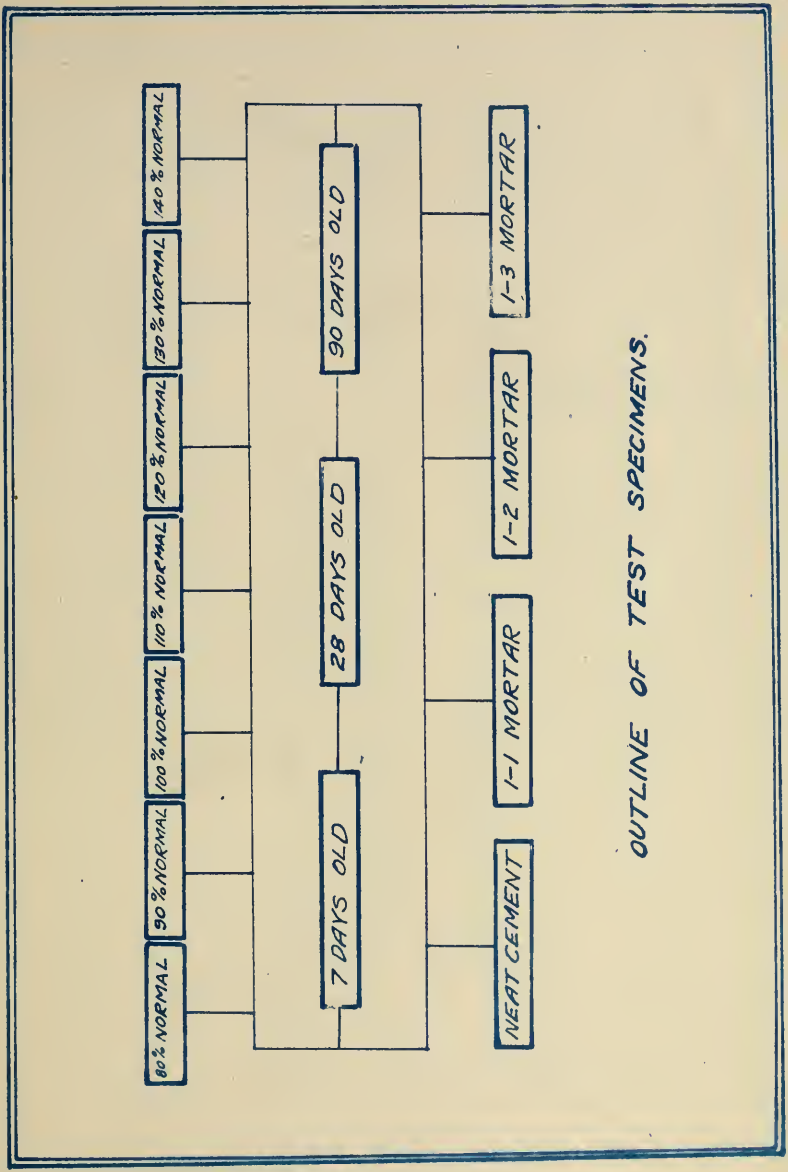
All work was done in the laboratories of the Armour Institute of Technology, Chicago, Ill.

Although, as a general rule, those interested will probably be more concerned with the final results than with the details of procedure, all laboratory methods and test figures are given in the hope that they may be of some use to someone who is engaged in similar work.

The writer is greatly indebted to Prof. Phillip C. Huntly, Associate Professor of Experimental Engineering at the Armour Institute of Technology, for much valuable advice and assistance, and wishes to express his thanks for the interest shown by Prof. Huntly in this work.

The writer also wishes to thank Mr. Dickinson, of the Marquette Cement Mfg. Co., for the chemical analysis of the cement used; and Prof. Duff A. Abrams, Professor in charge of the Structural Materials Research Laboratory at Lewis Institute, for his kindness in furnishing the color chart used in sand analysis.

For illustrations of their products,



OUTLINE OF TEST SPECIMENS.

Fig. 1

the writer is indebted to the Tinius Olsen Testing Machine Co., Riehle Bros. Testing Machine Co., Howard & Morse, and The Bausch & Lomb Optical Co.

All Calculations contained herein were made by the writer, and where accuracy was required to only three significant figures, were made on the slide rule.

Roy Monroe Singer.

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Compression

7 Days 124

28 Days 125

90 Days 126

STRENGTH-CONSISTENCY CURVES

Primary

Tension

7 Days 127

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90 Days 129

Average

Compression

7 Days 131

28 Days 133

90 Days 135

Tension

7 Days 137

28 Days 139

90 Days 141

General

Compression 144

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STRENGTH-AGE CURVES

PRIMARY

Compression

Neat Cement 148

1 - 1 Mortar 148

STRENGTH-AGE CURVES

Primary

Compression

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1 - 3 Mortar 151

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CHAPTER I

PRELIMINARY DISCUSSION

THE EFFECT OF QUANTITY OF MIXING WATER ON THE STRENGTH OF VARIOUS PORTLAND CEMENT MORTARS.

Cement mortar is made of three materials-cement, sand, and water but many of those engaged in construction work are too ready to overlook and to under - estimate the importance of the last named ingredient. The cement and sand proportions are generally very carefully looked after though only too often the quantity of water is looked upon as a matter of minor importance, a fact which is much to be deplored.

In times past the degree of wetness of a mortar was spoken of as its "plasticity" and not much attention was paid to it. Cement mortar was said to have three degrees of "plasticity": dry, medium, and wet.

When cement mortar was mixed the quantity of mixing water to be used was left to the discretion of the man doing the mixing; the only specification made was that the resulting mixture should be dry, medium, or wet. As the results of

the experiments contained herein show that the strength of cement mortar is dependent upon the amount of water used in its manufacture, it is seen that the strength of the mortar was entirely dependent upon the laborer's conception of "dry, medium, or wet".

Such a conditiom of affairs, regrettable as it may seem,is quite the vogue to-day among not only the smaller contractors but also with some of the larger construction companies. Some of them have not as yet come to recognize the necessity for the regulation of the amount of mixing water used.

According to Hool & Johnson in their "Concrete Engineer's Handbook" , the functions of water in cement mortar are four in number and are as follows:

I. Water reacts chemically with the cement to form a binding material which unites the otherwise non - cohering sand.

2. Water operates to flux both dissolved and undissolved cementing substances over the surfaces of the sand grains renering possible extensive and close adhesion by carrying the substances into the minute and multitudinous surface

irregularities of the particles, where they are absorbed as water is later absorbed or evaporated.

3. Water acts as a lubricant between sand particles so that poacement of harsh and irregular materials in moulds and forms is rendered easy.

4. Water itself occupies space in the mass.

WATER AS A CHEMICAL REAGENT/

The first function of water is basic and is of the greatest importance for without water the manufacture of cement mortar would be impossible. It is easily seen that the use of insufficient water would make the reaction between the water and cement incomplete and would result in a mortar which would be materially reduced in strength. On the other hand, the addition of too much water would cause an undue dilution and the strength of the resulting product would be affected in a manner similar to that of glue to which an excess of water has been added.

The behavior of cement in the process of hardening and setting is quite an interesting sub-

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

ject and much time and study havenbeen devoted to it by some of the foremost men in the field of experimental research. No definite result, such as a simple chemical equation to explain the process, has as yet been given to science and it is quite unlikely that such an expression will ever be discovered.

Due to the fact that cement consists of several different materials which are mixed mechanically the expression of the process by a simple equation is further complicated because even perfectly mixed cement may contain a larger amount of unchanged material after hardening and setting. A further complication is introduced by the formation of indefinite colloids.

"Le Chatelier, in the course of his experiments, found that thin sections of hardened cement contained large doubly refracting crystals which consisted of calcium hydroxide. Taking into account the further fact that the only calcium silicate which is stable in contact with water is a hydrated form of the metasilicate, he looked upon the principal reaction as being the hydrolysis of a tricalcium silicate, with the formation of

calcium hydroxide and hydrated monocalcium silicate.

The difficulty in the expression of the above theory in an equation was the lack of knowledge of the number of materials of the water of crystallization. Le Chatelier assumed a definite figure but since his figure was only an assumption, the number of molecules of the water of crystallization are best represented by the figure x. By so doing we obtain the equation:[i]

$$3CaOSIO_2 + aq \longrightarrow CaOSiO_2(x)H_2O + 2Ca(OH)_2$$

It is evident that only a part of the change can be expressed by this equation as the aluminates also share in the hydration. They, therefore, were assumed to react with the lime and water to form a more basic aluminate. This idea of the hydrolysation of Portland Cement into free lime and "such compounds of lime with silica and of lime with alumina as can be formed in a wet way", had already been made by A. Winkler."

From the foregoing it will readily be seen that the chemistry of the action of cement

[i] From Desch's "Chemistry and Testing of Cement."

and water is a subject which offers a wide field for investigation and is quite beyond the scope of this work.

WATER AS A FLUX.

The action of water as a flux whereby the cement is brought into intimate contact with the aggregate is to obvious to require any explanation. Such action, however, may be seriously hampered by an excess of water or by an insufficient supply. If too much water is present the solution may be weakened due to a greater separation of the particles held in suspension. Not only is this effect produced but also the minute crevices and irregularities of the aggregates may become filled with the surplus water and thus prevent the required intimate contact with the cement.

If not enough water is present the cement will not be carrued into the minute irregularities of the aggregate.

WATER AS A LUBRICANT.

Water,as a lubricant for cement mortar, is one of the excuses whereby the careless contractor has justified himself in using it to excess.

The method of distribution of mortars most in vogue on large works, at the present time, is the scheme of chuting it from elevated towers, and is dependent for its efficiecy upon the ease with which the materials slide down the inclined chute.

It is evident that the addition of more water will promote the efficiency of distribution but it is very questionable as to whether the contractor is justified in sacrificing strength for ease of distribution.

It should be borne in mind that due to the action of mixingccement is constantly hydrating and large quantities of hydrated lime are formed in the process of hydration. The hydrated lime itself acts as a lubricant. In fact, the value of hydrated lime as a lubricant to promote the easy passage of the mortar through the chute

is becoming recognized, and has resulted in the practice of adding small percentages of lime to cement mixtures for the purpose of making the material slide more easily. Experiments have shown that up to a certain point the addition of small percentages of hydrated lime to cement mortars does not in the least affect the final strength. (See thesis by Hook and Kneupfer "A Study of the Effects Produced on Portland Cement Mortars By the Addition of Various Percentages of Hydrated Lime".)

This would tend to show that ease of transportation should be no excuse for the presence of an excess amount of surplus water.

WATER AS OCCUPYING SPACE IN THE MASS..

As tomthe fourth function of water, its property to occupy space in the mass, one can almost say that it is due to this quality that the final strength of a mortar is impaired.

When mortar is dumped into a form all three constituents, cement, aggregate,and water occupy space. If the form leaks, a thing which should not happen, much of the excess water will

run off and carry with it a good portion of the cement particles and will form "laitance", of which more will be said later. The final strength of the material in the forms will thus be materially weakened due tomthe loss of a part of the cement.

If the form does not leak, the excess water will be retained, and due tomits incompressibility will occupy space in the mass. When the forms are removed, the excess water will work its way to the outside of the piece much after the fashion of water seeping through a porous rock. Upon the loss of this excess water, voids will be left, and instead of a solid moulded piece the unit will be honeycombed throughout with small passages and thus be materially weakened.

There can be no question as to the fact that water voids, formed by excess water, are the chief causes for porosity in a mortar. These voids, which at one time contained water, become passageways and traps for penetrating and percolating waters, thus making a "water-

proof" mortar impossible.

Another effect, due it part to excess water, is the existence of so-called "shrinkage cracks". [i] They are of a general type and so universal as to be viewed by the majority either with eyes unseeing or with the contempt that comes with familiarity. Their importance, both as a condition and an indicator of internal processes is, however, not to be underestimated.

Shrinkage cracks are of a general type, as shown in Fig. 2, irregular in line, and radiating from a common center, usually a pore of greater or less size. This is to be expected inasmuch as a pore is at least a possible point of egress for water.from the mass immediately surrounding. Further, flow is freest from such an open center so that under evaporation or other processes it soon becomes a point of dryness; and inasmuch as it is already a point of weakness, relief planes radiate from it gradually as the drying proceedsiinward, until shrinkage stresses are balanced by internal resistance.

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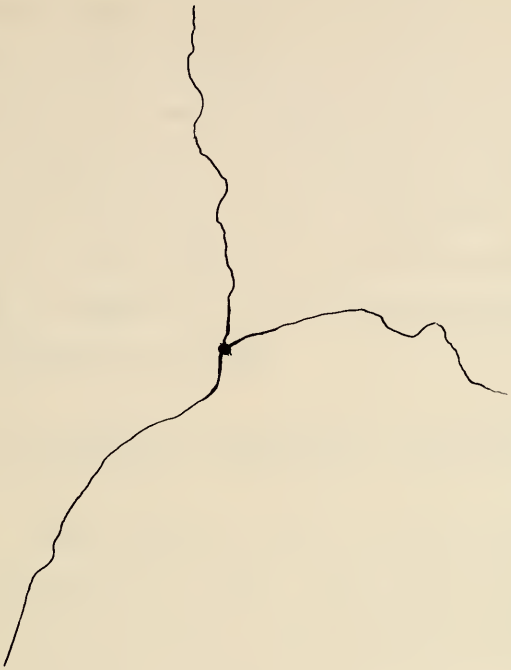
[i] From Hool & Johnson's "Concrete Engineer's Handbook".



FORM OF A SHRINKAGE CRACK.

Proof of the existence of these voids is quite apparent to anyone who has ever placed moulded specimens in water. If, immediately after placing the piece in water, it is removed and helf close to the ear, a sucking sound will be noticed. This is due to the displacement of the air in the voids by the water. For further treatment of this subject of voids the reader is referred to Chapter VII where photomicrographic illustrations are included.

EFFECT OF FROST AND CONCRETING IN COLD WEATHER.

The presence of these voids in articles manufactured of cement mortar which are exposed to the elements, such as cement benches, posts, or ornamental work, are really dangerous in that they subject the pieces to the same risks as is encountered by any porous rock due to frost disruption.

Concreting in cold weather, which is always hazardous, is made more so by the presence of too much water. The production of cement-

ing strength due to the action of the water with cement has been found to be only one-fourth as rapid at 40 degrees F. as at 50 degrees F., and less than one-ninth as rapid as at 70 degrees F. Since the speed of reaction is so materially decreased by lower temperatures, it is not improbable that some of the water may freeze before the reaction is completed.

Materials poured and subjected to the above conditions cannot develope even a small part of their calculated strength, and when the forms are removed and warm weather sets in nothing can result except complete collapse. When pouring must be done in cold weather, as is often necessary on construction work which must be completed irrespective of the seasons, the amount of water used in mixing is quite as important, in the final analysis, as is the amount of cement.

LAITANCE.

One of the most common effects due to the presence of excess water in cement mortar is the formation of what is known as "laitance".

Laitance is a material of womewhat the same chemical composition as normal Portland cement except for its larger loss on ignition. It consists largely of amorphous material of an isotropic nature; that is, it does not affect polarized light. It has practically no setting qualities. A chemical analysis by Mr. Clifford Richardson, taken from Taylor & Thompson's "Concrete, Plain & Reinforced", is given below:

SiO_2	16.00 %
Al_2O_3 and Fe_2O_3	8.66
Ca O	47.40
Mg O	2.40
Loss on ignition	25.60

Laitance is particularly noticable in the construction of retaining walls or tanks where pouring has been stopped before the moulds

LAITANCE

MAGNIFIED 20 DIAMETERS

were filled and then another layer of material placed to fill the moulds. It makes its appearance as a whitish or light-colored line marking the plane to which the mould was first filled. Such marks or lines are called "day's work planes". They are caused by the heavier materials sinking to the bottom of the forms and forcing to the surface the lighter solution of cement. It should be remembered that it is not possible to secure a bond between new mortar and old mortar which is covered by a layer of laitance.

CEMENT FLOORS AND WALKS.

In the laying of cement floors and walks, the percentage of water used is of extreme importance. If excess water is used, the lighter materials will rise to the top and form a chalky, easy-wearing surface which is easily broken down. It must be born in mind that the surface of a floor should be the toughest and most resistant part, and the amount of

water used when mixing the cement should therefore be just enough to produce a workable mix.

CONCLUSION.

The topic of consistency resolves itself into a matter of dollars and cents. The man who willfully neglects such an important factor as consistency is not securing the greatest strength from his cement and is therefore losing money. It is certainly more economical to use the full strength of a mortar rather than to waste a good part of it by the use of too much water in mixing.

The reply of construction men to those who advise them against using too much water in mixing is that the factor of safety is large, that the unit stresses are low, and that the present mode of distribution on the job is the most economical yet devised. Is it no possible, however, that by using a differ nt method of distribution whereby the correct percentage of water could be used, the greater strength resulting therefrom would offset the increased cost?

Is it entirely impossible that if such a thing became general practice the unit stresses would eventually be increased, thus permitting the use of less material?

It is something to think about. Stranger things have happened.

CHAPTER II

DISPOSITION OF MATERIALS

DELIVERY

The cement and sand used in this work was purchased in the open market in Chicago. When ordering the sand no specification was made except that commercial torpedo sand be furnished. When the sand was received, it was very wet and the particles ranged in size from 1/2" in diameter to dust which would pass a No. 200 sieve. Some stones as large as 2" in diameter were found to be included.

The cement, of which six sacks were purchased, was manufactured by the Marquette Cement Mfg. Co. It was delivered on a cloudy day and carried directly from the truck into the laboratory and placed on the dry concrete floor. The six sacks were mixed in the following manner to obtain one "average cement".

METHOD OF OBTAINING "AVERAGE CEMENT"

The six sacks were separated into two groups of three sacks each. One sack from each

group was spread to cover about nine square feet of dry cement floor. Then a second bag from each group was spread over the contents of the first, and the third spred over the contents of the second. Each group was thoroughly mixed by being turned several times with a dry shovel, and then the two groups were mixed with each other.

Six samples were taken from six different points of the "average cement" as it lay on the mixing floor and were used in making the preliminary tests. These samples were stored in well corked glass containers. After the test samples were taken out, the remainder of the cement was immediately placed in water-tight, metal storage bins.

PRELIMINARY TREATMENT OF SAND

Before use, the sand was firstsscreened to pass a number 4 sieve. It was then laid on zinc topped tables in one-inch layers and left to dry for three days at a temerature ranging from 60 to 70 degrees F. Most of the moisture was driven off in this manner as was indicated by the large amount of dust which arose when the sand

was disturbed. Six batches of sand were screened and dried in this manner and a sample taken from each batch to be used in making the various tests as outlined in chapter III.

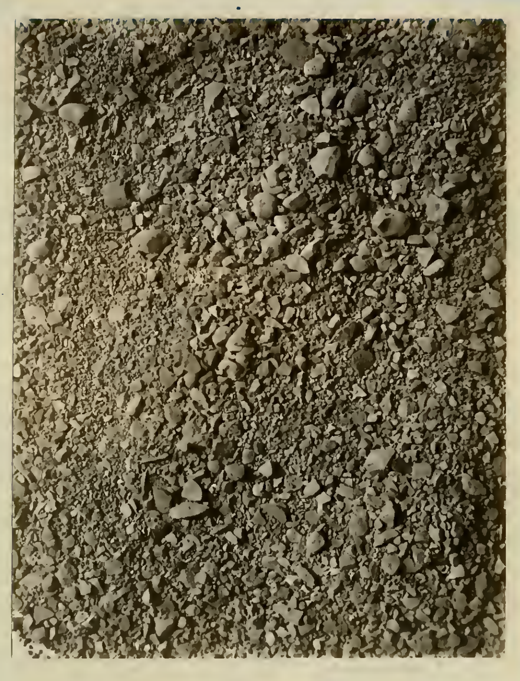
In Fig. 3, page 20, is shown an illustration of the sand used in the tests , after screening and drying.

DETERMINATION OF WEIGHT PER CUBIC UNIT

Immediately after being received, the weight per cubic centimeter of both sand and cement was determined in order that the percent of water used in mixing might be expressed for both proportions by weight and by volume.

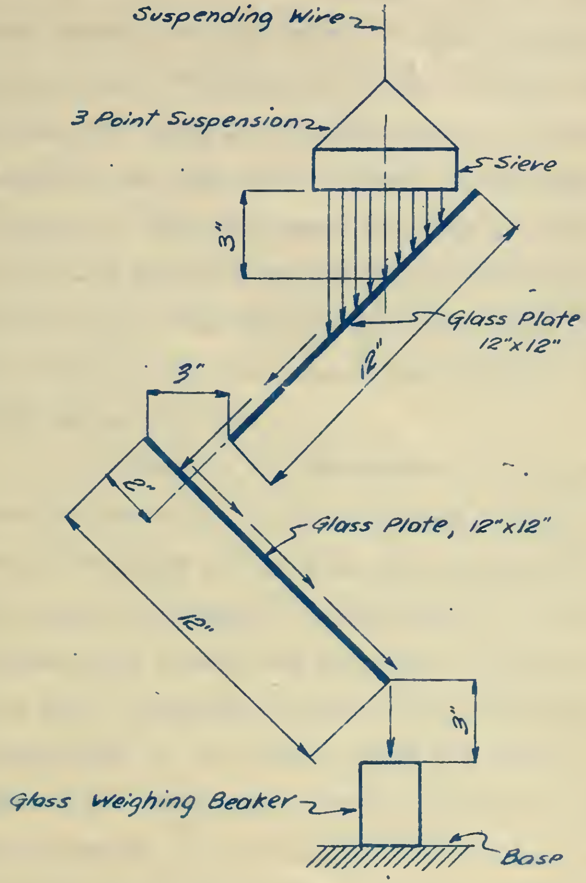
For this determination the apparatus shown in Fig. 4, page 2I was used. This consists of a lippless glass beaker of approximately 450 cubic centimeters capacity, two I2" x I2" glass plates each arranged at an angle of 45 degrees with the vertical and perpendicular to each other, and one No. 4 sieve for sand , and one No. 50 sieve for cement.

The material was placed in the sieve



SAND USED.   ACTUAL SIZE.
AFTER PASSING NO. 4 SIEVE.

Fig. 3.



Apparatus for Determination of Weight per Cubic Centimeter

Fig. 4

and the sieve suspended over the upper glass plate. When the sieve was agitated the material came through and was deposited upon the upper glass plate. The velocity of fall was thus intercepted, the material sliding down the smooth glass plane and falling upon the lower plate. Here the velocity of fall was again intercepted, the material slid slowly down the second glass plane and fell into the beaker. When the beaker was filled, the material was leveled by drawing a straight edge across the top.

Checking the velocities of the particles by means of the glass planes caused the materials to slide slowly down the planes and to drop equal distances with very nearly the same speeds. This caused the particles to separate from each other and prevented the formation of large voids in the beaker which may have occured if the particles had been allowed to become concentrared. It also tended to eliminate uneven packing in the beaker due to having some particles projected into it with greater force than others and thus was the means of obtaining something near a constsnt when filled beakers of the

same materials were weighed.

The cubic capacity of the beaker was obtained as follows: the beaker was weighed, filled with water, and weighed again. Since water at 20 degrees C. weighs one gram per cubic centimeter, the difference in the two weighings would give the cubic capacity of the beaker.

In Table I, page 24, are shown the results of twelve weighings from which the following averages were obtained:

Weight of emptybbeaker	7I.0 gr.
Weight of beaker of water	540.I gr.
Weight of beaker of sand	843.5 gr.
Weight of beaker of cement	587.5 gr.

From the above figures the capacity of the beaker and the weights per cubic centimeter of the materials were calculated as shown below.

Capacity of beaker is equal to 540.I minus 7I.0 or .... 469.I cubic centimeter .

Weight per cubic centimeter of sand is equal to .... I.79 gr. per cubic cent'ter.

TABLE 1

DATA FOR DETERMINATION OF WT. PER CUBIC UNIT				
TEST NUMBER.	CONTENTS OF VESSEL			
	AIR	WATER	CEMENT	SAND
1	71.0	540.0	588.3	842.5
2	71.1	540.1	586.8	844.0
3	71.0	539.8	588.0	842.5
4	71.0	540.4	586.5	847.8
5	71.0	540.3	587.0	840.0
6	70.9	540.2	588.5	846.2
7	71.0	539.9	586.5	843.8
8	71.0	540.1	587.4	845.0
9	71.1	540.3	588.3	839.0
10	71.0	540.1	587.1	847.2
11	71.0	540.0	587.6	840.8
12	71.0	539.7	588.0	843.1
AVERAGE.	71.0	540.1	587.5	843.5

Figures are weights in grams.

Weight per cubic centimeter of cement is equal to .... I.25 grams.

The weights per cubic centimeter of sand and cement were calculated by the following formula:

$$W = \frac{W_m - W_e}{C}$$

Where:

W = Weight per cubic centimeter.

W_m = Weight of filled beaker, in grams.

W_e = Weightnof empty beaker, in grams.

C = Capacity of beaker in cubic centimeters,

Preceding the making and testing of the specimens from which the conclusions in Chapter VII were drawn, the following preliminary tests were made:

On Cement.

I. Specific Gravity.
2. Fineness.
3. Normal Consistency.
4. Soundness.
5. Time of Set.

On Sand.

I. Sieve Analysis.
2. Impurities.
3. Percent of Voids.
4. Specific Gravity.

In making these preliminary tests, the specifications of the American Society for Testing Materials were followed as closely as possible, and where any deviation from these specifications was made, the changes were carefully noted.

To the best of the writer's knowledge,

no standard tests for sand have as yet been officially adopted by the American Society for Testing Materials. The sand tests included Herin, though not standard, have proved to be very satisfactory, and in lieu of any other definite methods od laboratory procedure, are used.

CHAPTER III

PRELIMINARY TESTS

LIST OF APPARATUS USED IN PRELIMINARY TESTS

Standard Apparatus for Accelerated Soundness Tests.

Howard and Morse Testing Sieve Agitator.

Nest of nine Sieves. (Nos. I0, 20, 30, 40, 50, 60, 80, I00, 200)

Nest of two Sieves. (Nos. I00, 200)

Weighing Scales.

Set of Weights. (I kg. to .0I gr.)

Vicat Apparatus.

Gillmore Needles.

Le Chatelier Apparatus.

Thistle Tube.

250 c.c. Glass Graduate.

I00 c.c. Glass Graduate.

I2 oz. Graduated Prescription Bottle.

Glass Plates.

Trowel. (4 inch.)

A typical chemical analysis of the cement used, furnished by Mr. Dickinson, of the Marquette Cement Mfg. Co., is given below.

SiO_2	22.26%
Fe_2O_3	2.86%
Al_2O_3	7.75%
CaO	62.21%
MgO	1.70%
SO_3	1.80%
Loss on Ignition	0.86%
Total	99.44%
Insoluble Residue	0.25%

SPECIFICATIONS
FOR
CEMENT TESTS

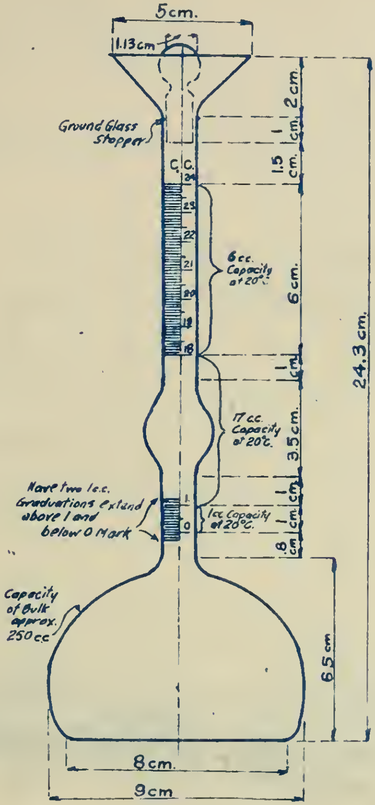
SPECIFIC GRAVITY

APPARATUS:

The determination of specific gravity shall be made with the standard Le Chatelier apparatus shown in Fig. 5, page 3I. This apparatus is standardized by the U.S. Bureau of Standards. Kerosene, free from water, or benzine not lighter than 62 degrees Baume shall be used in making this determination.

METHOD:

The flask shall be filled with the liquid to a point on the stem between zero and the I c.c. mark and 64 grams of cement, of the same temperature as the liquid, shall be slowly introduced, taking care that the cement does not adhere tomthe inside of the flask above the liquid and tomfree the cement from air by rollin the flask in an inclined position. After all the cement is introduced the level of the liquid will rise to some division of the graduated neck; the difference between readings is the vol-



LE CHATELIER APPARATUS.

Fig. 5

ume displaced by 64 grams of cement. The specific gravity shall then be obtained from the formula:

$$\text{Specific Gravity} = \frac{\text{Weight of Cement. (In gr.)}}{\text{Displaced Volume. (In c/c.)}}$$

The flask, during the operation, shall be immersed in water, in order to avoid variations in the temperature of the liquid in the flask, which should not exceed 0.5 degree Centigrade. The results of repeated tests shall agree within 0.0I.

The determination of specific gravity shall be made on the cement as it is received; if it falls below 3.I0 a second determination shall be made after igniting the sample.

FINENESS

APPARATUS:

Wire cloth for standard sieves for cement shall be woven (not twilled) from brass

bronze, or other suitable wire, and mounted without distortion on frames not less than one and one-half (I - I/2) inch below the top of the frame. The sieve frames shall be circular, approximately 8 inches in diameter and may be provided with a pan and a cover.

A standard No. 200 sieve is one having nominally an 0.0029 inch opening and 200 wires per inch standardized by the U. S. bureau of standards, and conforming to the following requirements:

The No. 200 sieve should have 200 wires per inch and the number of wires in any whole inch shall not be outside the limits of I92 to 208. no opening between adjacent parallel wires shall be more than 0.0050 inches in width. The diameter of the wire should be 0.002I inches and the average diameter shall not be outside the limits 0.00I9 to 0.0023 inches. The value of the sieve as determined by sieving tests made in conformity with the standard specifications for these tests on a standardized cement which gives a residue

of 25 to 20 percent on the No. 200 sieve or on any other similarly graded material, shall not show a variation of more than I.5 percent above or below the standards maintained at the U. S. Bureau of Standards.

METHOD:

The test shall be made with 50 grams of cement. the sieve shall be thoroughly clean and dry. the cement shall be placed on the No. 200 sieve with the pan and cover attached if desired, and shall be held in one hand in a slightly inclined positionso that the sample will be well distributed over the sieve, at the same time gently striking the side about I50 times per minute against the palm of the other hand on the up stroke. the sieve shall be turned every 25 strokes about one-sixth (I/6) of a revolution in the same direction. the operation shall continue until not more than 0.05 gram passes through in one minute of continuous sieving. the fineness shall be determined from the weight of the residue on the sieve expressed as a perent-

age of the weight of the original sample. Mechanical sieving devices may be used but the cement shall not be rejected if it meets the fineness requirement when tested by thhe han method described.

PERMISSIBLE VARIATION:

A permissible variation of one will be allowed, and all results in excess of the specified limit but within this permissible variation shall be reported as 22 Percent.

DEVIATION FROM SPECIFICATIONS:

After the determination of fineness as outlined above, the residue on the No. 200 sieve was placed on a No. 100 sieve and the operation repeated. the weight of the residue on the No. 100 sieve was then expressed as a percentage of the weight of the original sample.

MIXING CEMENT PASTES AND MORTARS

METHOD:

The quantity of dry material to be mixed at one time shall not exceed 1000 grams or be less than 500 grams. The proportions of cement or cement and sand shall be stated by weight in grams of the dry materials; the quantity of water shall be expressed in cubic centimeters. (1 c.c. of water = 1 gram.) The dry materials shall be weighed, placed upon a non-absorbent surface, thoroughly mixed dry if sand is used and a crater formed in the center, into which the proper percentage of clean water shall be poured; the material on the outer edge shall be turned into the crater by the aid of a trowel. After an interval of one-half (1/2) minute for the absorption of water the operation shall be completed by continuous, vigorous mixing, squeezing and kneading with the hands for at least one minute.

The temperature of the room and the mixing water shall be maintained as nearly as possible at 21 degrees C. (70 degrees F.)

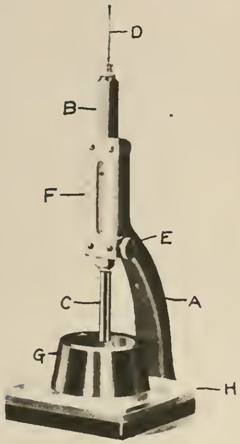
NORMAL CONSISTENCY

APPARATUS:

The Vicat Apparatus, Fig. 6, page 38, consists of frame A bearing a movable rod B weighing 300 grams, one end C being one cm. in diameter for a distance of 6 cm., the other having a removable needle D, I mm. in diameter, 6 cm. long. The rod is reversible and can be held in any desired position by a screw E, and has midway between the ends a mark F which moves under a scale (graduated to millimeters) attached to the frame A. The paste is held in a conical hard rubber ring G, 7 cm. in diameter at the base, 4 cm. high, resting on a glass plate H about IO cm. square.

METHOD:

In making the determination, 500 grams of cement, with a measured quantity of water, shall be kneaded into a paste as described before, and quickly formed into a ball with the hands, completing the oper-



VICAT APPARATUS

Fig. 6

ation by tossing it six times from one hand to the other, maintained about six inches apart; the ball resting on the palm of one hand shall be pressed into the larger end of the rubber ring held in the other hand, completely filling the ring with paste; the excess at the larger end shall then be removed by a single movement of the palm of the hand; the ring shall then be placed on its larger end on a glass plate and the excess paste at the smaller end sliced off at the top of the ring by a single oblique stroke of the trowel held at a slight angle with the top of the ring. During these operations care shall be taken not to compress the paste. The paste confined in the ring, resting on the plate, shall be placed under the rod, the larger end of which shall be brought in contact with the surface of the paste; the scale shall then be read and the rod quickly released. The paste shall be of normal consistency when the rod settles to a point IO mm. below the original surface in one-half (I/2)

minute after being released. The apparatus shall be free from all vibrations during the test. Trial pastes shall be made with varying percentages of water until the normal consistency is obtained. The amount of water equired shall be expressed in percentage by weight of the dry cement.

The consistency of standard mortar shall depend upon the amount of water required toproduce a paste of normal consistency from the sample of cement. Having determined the normal consistency of the sample, the consistency of standard mortar made from the same sample shall be as indicated in Table 2, page 40.

The values given in Table 40 are in percentage of the combined dry weights of cement and standard sand.

DETERMINATION OF SOUNDNESS

APPARATUS:

A steam apparatus which can be maintained at a temperature between 98 and

TABLE 2

PERCENTAGE OF WATER FOR STANDARD MORTARS.			
PERCENTAGE OF WATER FOR NEAT CEMENT PASTE OF NORMAL CONSIST'CY.	PERCENTAGE OF WATER FOR ONE CEMENT, THREE STD. OTTAWA SAND.	PERCENTAGE OF WATER FOR NEAT CEMENT PASTE OF NORMAL CONSIST'CY.	PERCENTAGE OF WATER FOR ONE CEMENT, THREE STD. OTTAWA SAND.
15	9.0	23	10.3
16	9.2	24	10.5
17	9.3	25	10.7
18	9.5	26	10.8
19	9.7	27	11.0
20	9.8	28	11.2
21	10.0	29	11.3
22	10.2	30	11.5

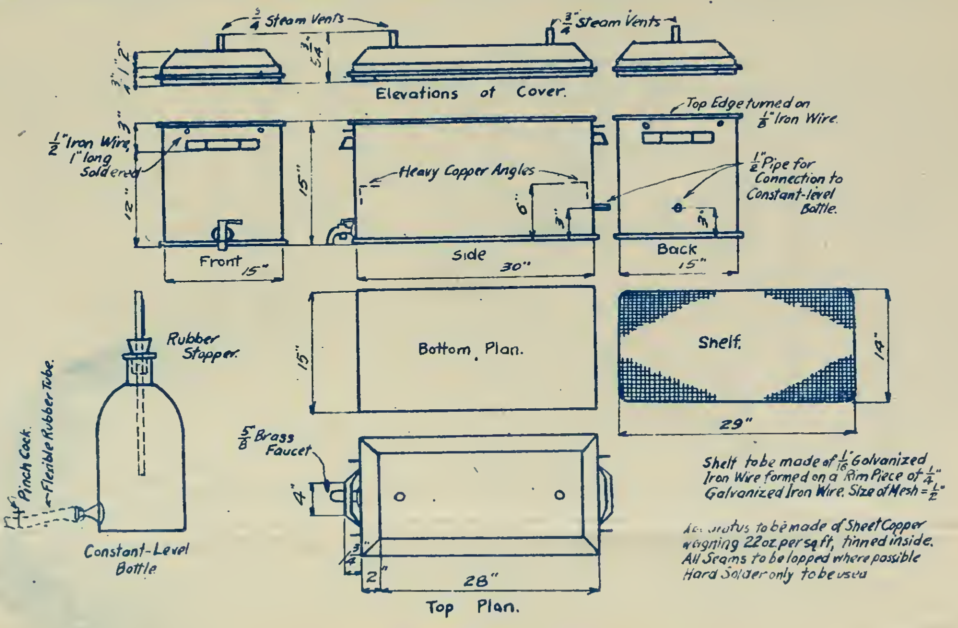
IOO degrees Centigrade or one similar to that shown in Fig. 7, page 42, is reccommended. The capacity of this apparatus may be increased by using a rack for holding the pats in an inclined or vertical position.

METHOD:

A pat from cement paste of normal consistency about three inches in diameter, one-half (I/2) inch thick at the center, and tapering to a thin edge shall be made on clean glass plates about 4 inches square, and stored in moist air for 24 hours. In moulding the pat, the cement paste shall first be flattened on the glass and the pat then formed by drawing the trowel from the outer edge towards the center.

The pat shall then be placed in an atmosphere of steam at a temperature between 98 and IOO degrees Centigrade upon a suitable support one inch above boiling water for 5 hours.

Should the pat leave the plate, distortion may be best detected with a str-



Shelf to be made of $\frac{1}{16}$" Galvanized Iron Wire formed on a Rim Piece of $\frac{1}{4}$" Galvanized Iron Wire. Size of Mesh = $\frac{1}{2}$"

Apparatus to be made of Sheet Copper weighing 22 oz. per sq ft, tinned inside. All Seams to be lapped where possible Hard Solder only to be used

APPARATUS FOR ACCELERATED SOUNDNESS TESTS.

Fig. 7

aight-edge applied to the surface which was in contact with the plate.

DETERMINATION OF TIME OF SETTING

The following are alternate methods, either of which may be used as ordered:

VICAT APPARATUS:

The time of setting shall be determined by means of the Vicat Apparatus as described before and as illustrated in Fig. 6, page 38.

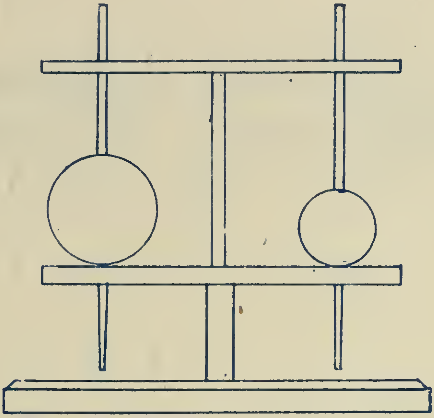
VICAT METHOD:

A paste of normal consistency shall be moulded in the hard rubber ring G as described before, and placed under the rod B, the smaller end of which shall be carefully brought into contact with the surface of the paste, and the rod quickly released. The initial set shall be said to have occurred when the needle ceases to pass a point 5 mm. above the glass plate in one-half (I/2) minute after being released; and the

final set, when the needle does not sink visibly into the paste. The etst pieces shall be kept in moist air during the test. This may be accomplished by placing them ina rack over water contained in a pan and covered with a damp cloth, kept from contact with them by means of a wire screen; or they may be stored in a moist closet. Care shall be taken to keep the needle clean, as the collection of cement on the sides of the needle retards penetration, while cement on the point may increasethe penetration. The time of setting is affected not only by the percentage and temerature of the water used and the amount of kneading the cement receives, but also by the temperature and humidity of the air, and its determination is therefore only approximate.

GILLMORE NEEDLES:

The time of setting shall be determined by the Gillmore needles. The Gillmore needles are shown in Fig. 8, page 45, and should preferably be mounted as illus-



LARGE NEEDLE

DIAMETER POINT = $\frac{1}{24}$ IN.
WEIGHT = 1 LLB.

SMALL NEEDLE

DIAMETER POINT = $\frac{1}{12}$ IN.
WEIGHT = $\frac{1}{4}$ LLB.

GILMORE NEEDLES.

Fig.8

trated.

GILLMORE METHOD:

The time of setting shall be determined as follows: A pat of neat cement paste about 3 inches in diameter, and one-half (I/2) inch in thickness with tapering edges and a flat top, mixed to normal consistency, shall be kept in moist air at a temperature maintained as nearly as practicable at 2I degrees Centigrade (70 degrees F.) The cement shall be considered to have acquired its initial set when the pat will bear, without apprecible indentation, the Gillmore needle one-twelfth (I/I2) inch in diameter, loaded to weigh one-fourth (I/4) pound. The final set has been acquired when the pat will bear , without apprecable indentation, the Gillmore needle one-twenty-fourth (I/24) inch in diameter, loaded to weigh one pound. In making the test, the needles shall be held in a vertical position, and applied lightly to the surface of the pat.

SPECIFICATIONS
FOR
SAND TESTS

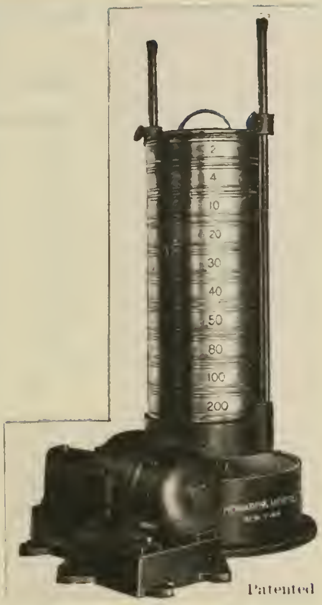
SIEVE ANALYSIS

APPARATUS:

The apparatus used in making the sieve analysis shall be a testing sieve agitator similar to that shown in Fig, 9, page 48. It may be either hand or mechanically operated. The sieves used shll be nine in - number and of the sizes and openings as given in Table 3, page 49. All weighing shall be done on an ordinary laboratory scale.

METHOD:

The sample to be tested shall consist of 500 grams of sand. All weights shall be to the nearest 0.I gram. The testing sieves shall be arranged in the following order with the No. IO sieve on the top: Nos. IO, 20, 30, 40, 50, 60, 80, IOO, 200. The 500 gram sample shall be placed on the No. IO sieve, a cover placed on the sieve, and the nest of sieves placed in the testing sieve agitator which shall be rotated at



TESTING SIEVE AGITATOR

Fig. 9.

TABLE 3

SIZES OF SIEVE OPENINGS.	
SIEVE NUMBER.	DIAMETER OF OPENING IN INCHES
10	0.073
20	0.034
30	0.022
40	0.015
50	0.011
60	0.009
80	0.007
100	0.0045
200	0.00275

the rate of approximately IOO R.P.M. for fifteen minutes. The residue on each sieve and the amount passing each sieve shall be expressed by weight as a percentage of the weight of the original sample.

TEST FOR ORGANIC IMPURITIES

APPARATUS:

The apparatus used in the test for organic impurities shall be a I2 oz. graduated prescription bottle and a sufficient stock of a three percent solution of sodium hydroxide made by dissolving I oz. of sodium hydroxide in enough water to make 32 oz.

METHOD:

The method used shall be the Abrams-Harder Field Test for Organic Impurities in Sands. Fill a I2 oz. graduated prescription bottle to the Four and one-half (4-I/2) oz. mark with the sand to be tested. Add the Three percent solution of sodium hydroxide until the volume of the sand and solution, after

shaking, amounts to 7 oz. Shake thoroughly and allow to stand for 24 hours. Observe the color of the clear liquid above the sand and compate with the color chart shown in Fig. 10, page 52.

PERCENT OF VOIDS

APPARATUS:

The percent of voids shall be determined by means of a graduated cylinder, about one inch in diameter and having a capacity of over 100 c.c., the height of the cylinder not to exceed 8 inches.

METHOD:

A known quantity of water shall be poured into the graduate and a reading taken. Moisture free sand shall be slowly admitted to the vessel in increments of about one-half (1/2) inch and each increment shall be compacted by gently striking the cylinder three times on a one-half (1/2) inch thick pad composed of

PLATE V.
PROC. AM. SOC. TEST. MATS.
VOL. XIX, PART I.
REPORT OF COMMITTEE C-9:
ORGANIC IMPURITIES IN SANDS.

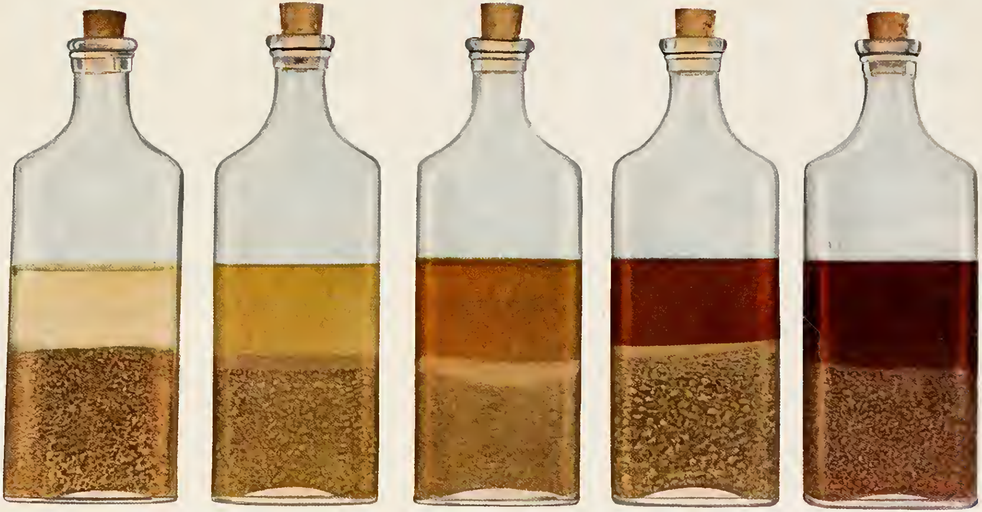


FIG. 1. FIG. 2. FIG. 3. FIG. 4. FIG. 5.

Sands suitable for use in high-grade concrete. (Figs. 1–2)

Sands which may be used in unimportant concrete work. (Figs. 2–3)

Sands which should never be used in concrete. (Figs. 3–4)

An unusually bad sand, soil or loam. (Figs. 4–5)

COLORS OF TREATED SANDS WITH SUGGESTED RANGES OF APPLICATION.

Fig. 10

several layers of felt or cloth.

The sand shall be introduced until the surface of the water and sand in the vessel are at the same level. The amount of sand u used shall be determined by reading the height of the surface of the sand in the vessel. The percent of voids in the sand shall be expressed by the following formula:

$$V = \frac{W}{S}(100)$$

Where:

V = Percent of vodids.

W = Volume of water, in c.c.

S = Volume of sand, in c.c.

SPECIFIC GRAVITY

APPARATUS:

The specific gravity of the sand shall be detremined by means of a graduated cylinder, about one inch in diameter and having a capacity of over 100 c.c., the height of the cylinder not to exceed 8 inches.

METHOD:

The graduate shall be partly filled with water and the height of the column of water read. Fifty grams of moisture-free sand shall then be admitted to the vessel, care being taken to permit the escape of air, and the height of the column of water again read. The specific gravitybof the sand shall be expressed by the following formula:

$$S.\ G. = \frac{S}{W}$$

Where:

S. G. = Specific Gravity.
S. = Weight of sand, in grams.
W. = Weight of water displaced, in gr.

RESULTS OF PRELIMINARY TESTS

On page 56 is given Table 4, showing the results of the preliminary tests on cement.

Table 5, page 57, is shown the results of the sand analysis.

Curve I, on page 58, is a graphical illustration of a part of Table 5. Diameters of particles passing the sieves,as ordinates,are plotted against percentage passing a given sieve, as abscissae.

Below are given the results of the miscellaneous sand tests.

THE Figures given below are the average of six tests:

Specific Gravity............	2.62
Percent of Voids............	28.3

RESULTS OF PRELIMINARY CEMENT TESTS.

SPECIFIC GRAVITY 3.105

PERCENT OF WATER FOR NORMAL CONSISTENCY 24.0

TIME OF SET:

VICAT APPARATUS

Initial set ....92 min.

Final set ....313 min.

GILLMORE APPARATUS

Initial set ....161 min.

Final set .... 379 min.

FINENESS:

Percent retained on No. 100 sieve 4.1

Percent retained on No. 200 sieve 19.6

SOUNDNESS:

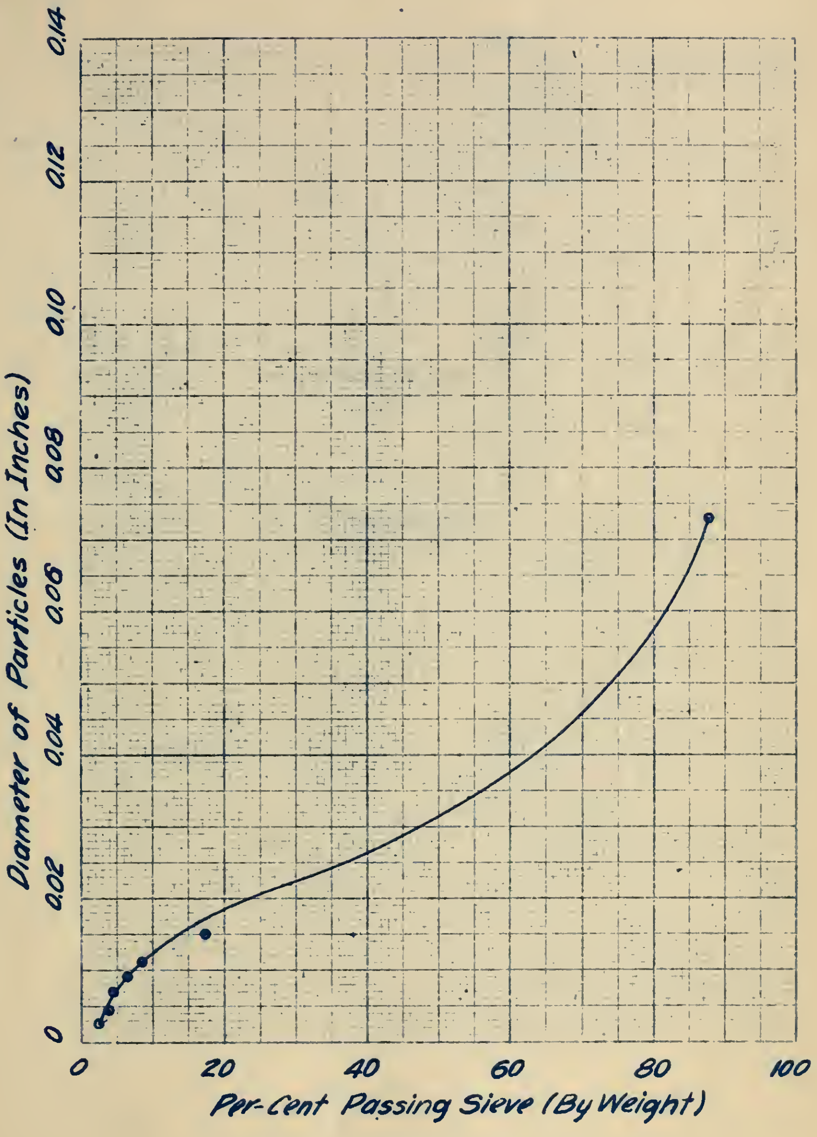
O.K.

EACH FIGURE IS THE AVERAGE OF SIX TESTS.

TABLE 5

RESULTS OF SAND ANALYSIS

SIEVE NUMBER.	SAMPLE NUMBER						AVERAGE OF SAMPLES		
	1	2	3	4	5	6	GRAMS	PERCENT	PERCENT
	GR. RET.	GR. RET.	GR. RET.	GR. RET.	GR. RET.	GR. RET.	RETAIN'D.	RETAIN'D.	PASSED.
10	56.0	70.2	69.0	57.2	49.8	62.5	60.8	12.2	87.6
20	168.0	170.4	164.4	168.8	152.5	174.0	166.4	33.3	54.3
30	130.5	121.5	120.8	127.0	130.5	124.4	125.8	25.1	29.2
40	61.2	56.2	51.0	59.6	66.5	53.5	58.0	11.6	17.6
50	43.6	44.4	38.6	44.2	51.5	48.2	45.1	9.0	8.6
60	11.2	9.0	11.0	10.6	12.2	8.0	10.4	2.1	6.5
80	7.4	8.2	11.2	7.5	9.0	5.0	8.1	1.6	4.9
100	4.0	2.5	6.4	4.5	5.0	5.8	4.7	0.9	4.0
200	4.6	3.0	7.8	5.4	6.2	4.5	5.3	1.1	2.9
PAN	12.8	13.8	15.2	14.2	16.4	13.2	14.3	2.9	--


0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
Diameter of Particles (In Inches)
0
20
40
60
80
100
Per-Cent Passing Sieve (By Weight)

Curve 1.

CHAPTER IV

FINAL TESTS

The following apparatus was used in the final tests:

60,000 Llb. Olsen Testing Machine.

1000 Llb. Riehle Tension Machine.

Fairbanks Scale.

Set of Weights. (1 kg. to 0.1 gr.)

18" x 12" x 1/4" Glass plates.

Trowels. (8", 4")

Tamper.

Oiling Swab.

2" x 4" Cylindrical Moulds.

3" x 6" Cylindrical Moulds.

Standard Tension Briquette Moulds.

Glass Weighing Jar.

250 c.c. Glass Graduate.

Damp Closet.

Water storage Basins.

Sand Storage Boxes.

AMOUNT OF MIXING WATER

The normal consistency of the cement having been previously determined, the amount of water necessary for the different percentages of normal consistency of the neat cement was easily calculated. However, much difficulty was experienced in arriving at the amount of water necessary to produce a similar "degree of placticity" in a mortar containing certain proportions of sand and cement.

Many methods were tried, including slump tests, penetration tests, and comparison by means of the senses, but there was so great a difference between the results of the various tests that the writer finally decided to discard all of his experimental data relative to the determination of consistencies of mortars of different proportions and to use Feret's Table of proportions and percentage of water.

It was not without grave consideration and much experimenting that this course was decided upon, for the use of Feret's Table for percentages of water for mortars of different proportions is subject to the following disadvant-

ages in this series of experiments:

Feret's Tables are for standard sand. Standard sand was not used in these experiments.

Variations in results may be expected if the sand used varies in moisture content.

Inasmuch as no exact method for determining comparative consistencies of mortars of different proportions has as yet been developed, as far as is known to the writer, Feret's Table, which is the average of results obtained by a large number of experimenters, was used, with an allowance made for the grade of sand used.

On page 62 is given Feret's Table for percentage of water for normal consistency of cement mortars of different proportions. This table was taken from Taylor and Thompson's "Concrete, Plain and Reinforced".

Table 7, page 63, shows the relation between the amounts of water as given in Feret's Table and the amounts of water actually used.

TABLE 6

FERET'S TABLE FOR PERCENTAGE OF WATER FOR CEMENT MORTAR OF NORMAL CONSISTENCY.

PERCENTAGE OF WATER FOR NORMAL NEAT CEMENT	PERCENTAGE OF WATER TO CEMENT PLUS STANDARD OTTAWA SAND.				
	PROPORTIONS CEMENT TO SAND BY WT.				
	1-1	1-2	1-3	1-4	1-5
18	12.5	10.5	9.5	8.9	8.5
19	12.8	10.7	9.7	9.0	8.6
20	13.2	10.9	9.8	9.2	8.7
21	13.5	11.2	10.0	9.3	8.8
22	13.8	11.4	10.2	9.4	8.9
23	14.2	11.6	10.3	9.6	9.0
24	14.5	11.8	10.5	9.7	9.1
25	14.8	12.1	10.7	9.8	9.3
26	15.2	12.3	10.8	10.0	9.4
27	15.5	12.5	11.0	10.1	9.5
28	15.8	12.7	11.2	10.2	9.6
29	16.2	13.0	11.3	10.4	9.7
30	16.5	13.2	11.5	10.5	9.8
31	16.8	13.4	11.7	10.6	9.9
32	17.2	13.6	11.8	10.8	10.0
33	17.5	13.8	12.0	10.9	10.1
34	17.8	14.1	12.2	11.0	10.2
35	18.2	14.3	12.3	11.2	10.4

TABLE 7

TABLE SHOWING RELATION BETWEEN AMOUNT OF WATER FOR STANDARD SAND AND AMOUNT OF WATER USED.

PROPORTIONS BY WEIGHT				
PROPORTIONS	NEAT	1-1	1-2	1-3
PERCENTAGES FROM FERET'S TABLE	24.0	14.5	11.8	10.5
PERCENTAGES ACTUALLY USED	24.0	13.8	11.1	9.8

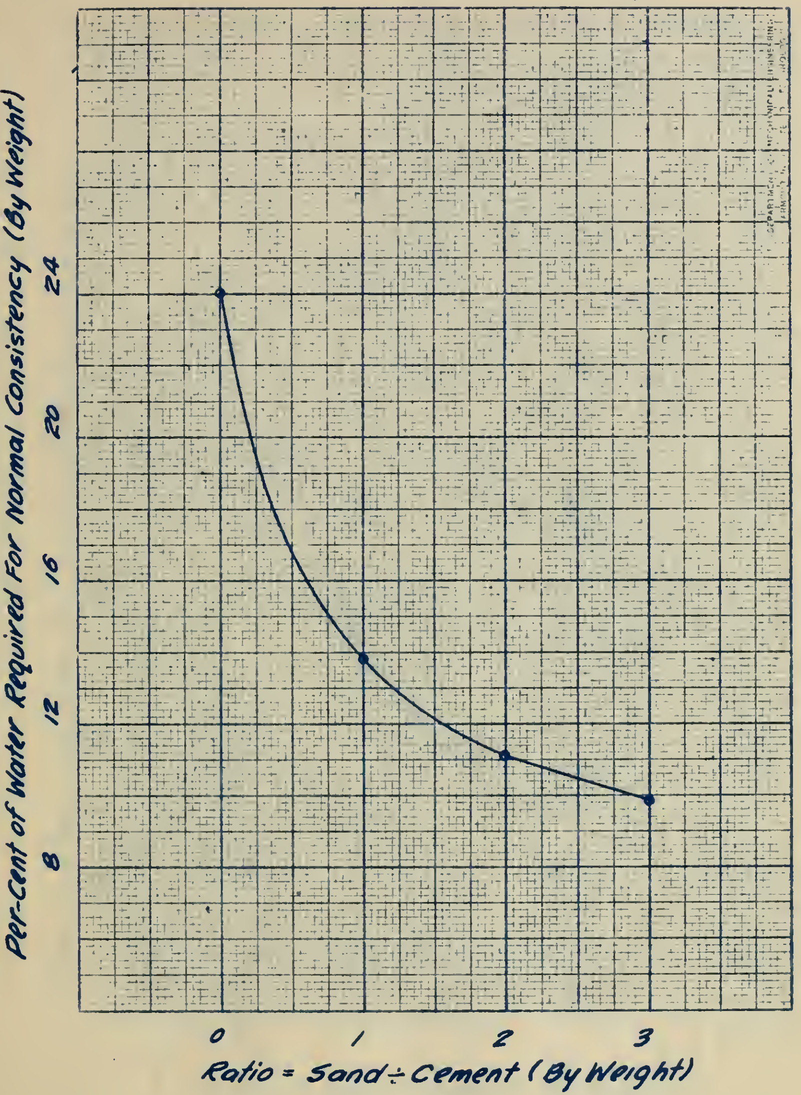
PROPORTIONS BY VOLUME				
PROPORTIONS	NEAT	1-1	1-2	1-3
PERCENTAGES FROM FERET'S TABLE	24.0	13.3	10.7	9.5
PERCENTAGES ACTUALLY USED	24.0	12.6	10.0	8.8

On page 65 is shown Curve 2, which illustrates graphically the relationship between percent of water for normal consistency and the ratio: sand divided by cement, when proportions are by weight.

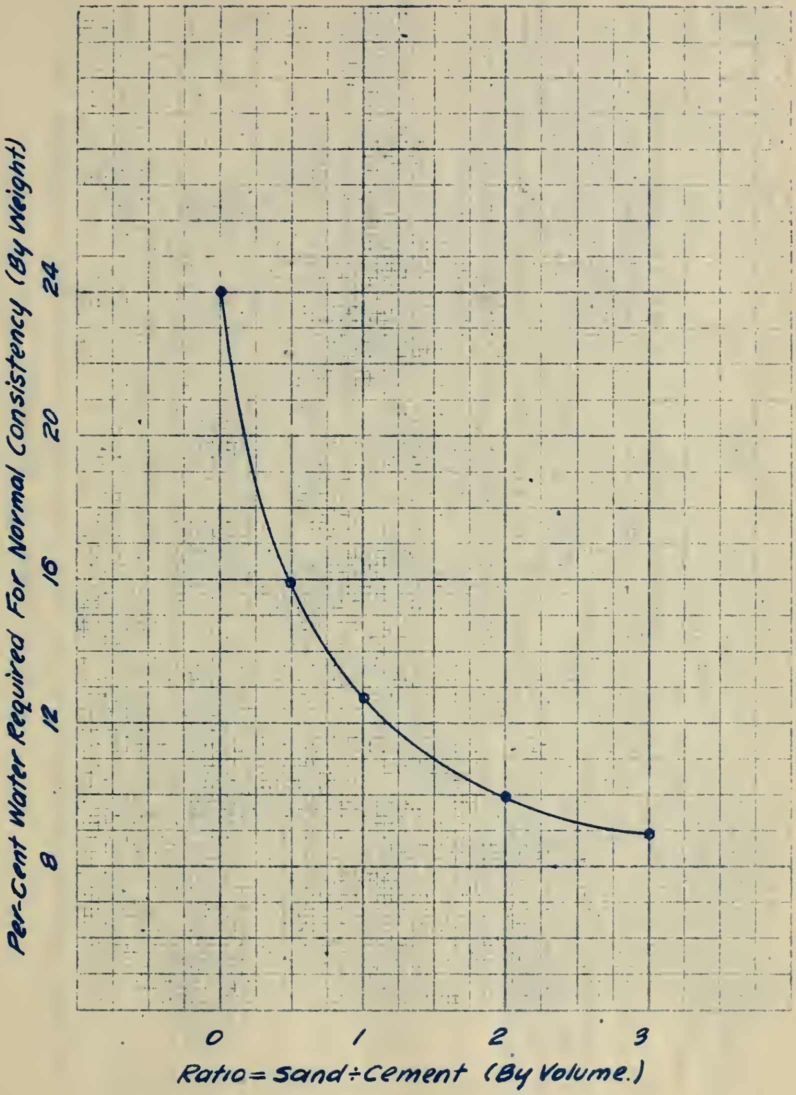
Curve 3, page 66, shows a similar relationship when the proportions are by volume.

In Table 8, page 67, is given the percentages of water required for different percentages of normal consistency of the different mortars when proportions are by weight. This is shown graphically in Curve 4, page 68.

Table 9, page 69, shows the percentages of water required for different percentages of normal consistency of the different mortars when proportions are by volume. Curve 5, page 70 is the graphical representation of Table9.


Per-Cent of Water Required For Normal Consistency (By Weight)
24
20
16
12
8
0
1
2
3
Ratio = Sand ÷ Cement (By Weight)

Curve 2


Per-Cent Water Required For Normal Consistency (By Weight)
24
20
16
12
8
0
1
2
3
Ratio = Sand ÷ Cement (By Volume.)

Curve 3

TABLE 8

PROPORTIONS BY WEIGHT

TABLE SHOWING PERCENTAGES OF WATER FOR DIFFERENT PERCENTAGES OF NORMAL CONSISTENCY

NEAT CEMENT MORTAR. NORMAL CONSISTENCY = 24.00 PERCENT

PERCENT OF NORMAL	80	90	100	110	120	130	140
PERCENT OF WATER	19.20	21.60	24.00	26.40	28.80	31.20	33.60

1—1 CEMENT MORTAR. NORMAL CONSISTENCY = 12.64 PERCENT.

PERCENT OF NORMAL	80	90	100	110	120	130	140
PERCENT OF WATER	10.11	11.38	12.64	13.90	15.17	16.43	17.70

1—2 CEMENT MORTAR. NORMAL CONSISTENCY = 9.98 PERCENT

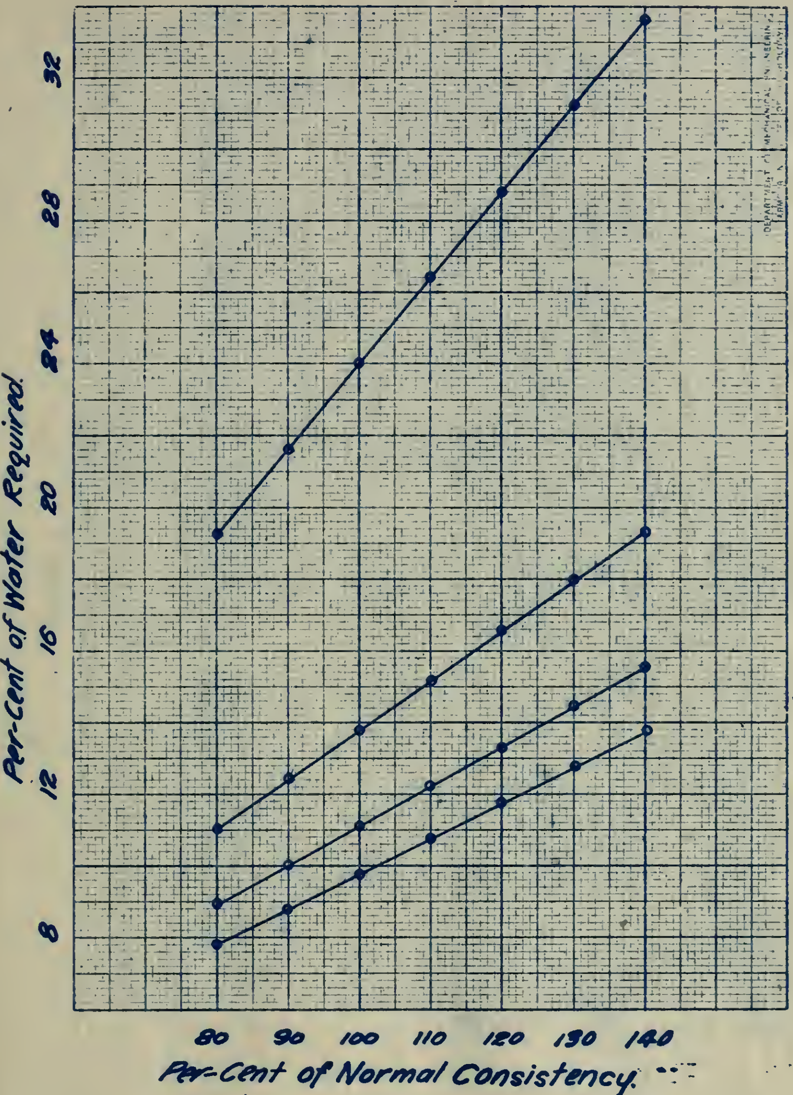
PERCENT OF NORMAL	80	90	100	110	120	130	140
PERCENT OF WATER	7.98	8.99	9.98	10.98	11.98	12.97	13.97

1—3 CEMENT MORTAR. NORMAL CONSISTENCY = 8.82 PERCENT

PERCENT OF NORMAL	80	90	100	110	120	130	140
PERCENT OF WATER	7.06	7.93	8.82	9.70	10.58	11.47	12.35

CORRECT TO ONE DECIMAL ONLY

PROPORTIONS BY WEIGHT



Curve 4.

TABLE 9

PROPORTIONS BY VOLUME

TABLE SHOWING PERCENTAGES OF WATER FOR DIFFERENT PERCENTAGES OF NORMAL CONSISTENCY

NEAT CEMENT MORTAR. NORMAL CONSISTENCY = 24.00 PERCENT							
PERCENT OF NORMAL	80	90	100	110	120	130	140
PERCENT OF WATER	19.20	21.60	24.00	26.40	28.80	31.20	33.60

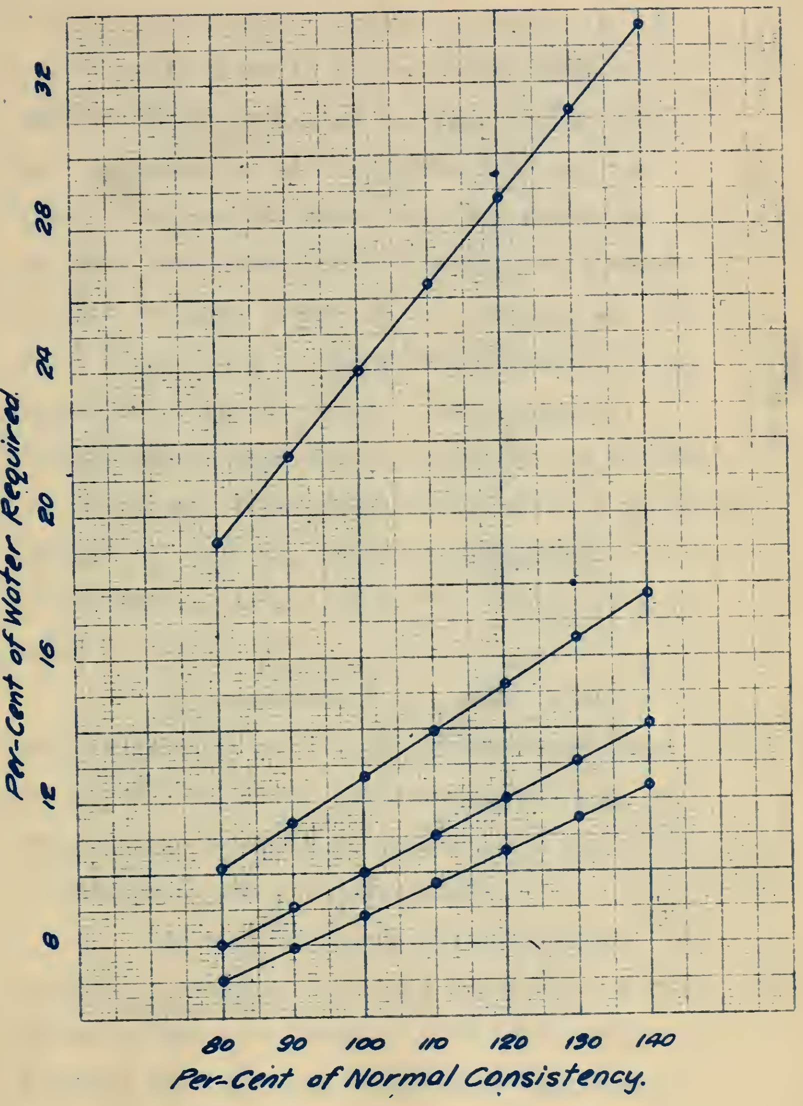
1—1 CEMENT MORTAR. NORMAL CONSISTENCY = 13.80 PERCENT							
PERCENT OF NORMAL	80	90	100	110	120	130	140
PERCENT OF WATER	11.04	12.42	13.80	15.18	16.56	17.94	19.32

1—2 CEMENT MORTAR. NORMAL CONSISTENCY = 11.10 PERCENT							
PERCENT OF NORMAL	80	90	100	110	120	130	140
PERCENT OF WATER	8.88	9.99	11.10	12.21	13.32	14.43	15.54

1—3 CEMENT MORTAR. NORMAL CONSISTENCY = 9.80 PERCENT							
PERCENT OF NORMAL	80	90	100	110	120	130	140
PERCENT OF WATER	7.84	8.82	9.80	10.78	11.76	12.74	13.72

CORRECT TO ONE DECIMAL ONLY

PROPORTIONS BY VOLUME



Curve 5.

MOULDING THE SPECIMENS

In order to secure proper comparative results for specimens of the same proportions and consistencies but of different ages, the seven, twenty-eight,and ninety day specimens of the same percentage and consistency were moulded from the same batch. By this method, any possible error in the comparative strengths of the specimens at different ages was eliminated. Slight errors might have occurred if the batches had been mixed separately, due to changes in temperature of the room, change in temperature of the mixing water, variations in the grading of the sand, and etc.

The materials for a given batch were proportioned by weight. The weights were carefully set down in the laboratory note-book, reference made to Table 8, page 67, and the amount of water required was calculated.

As each container of dry materials was weighed, it was dumped onto a No. 6 sieve which rested on the zinc-topped mixing table. When the weighing was completed and all the dry materials for the batch had been placed on the sieve, the

[illegible]

[illegible]

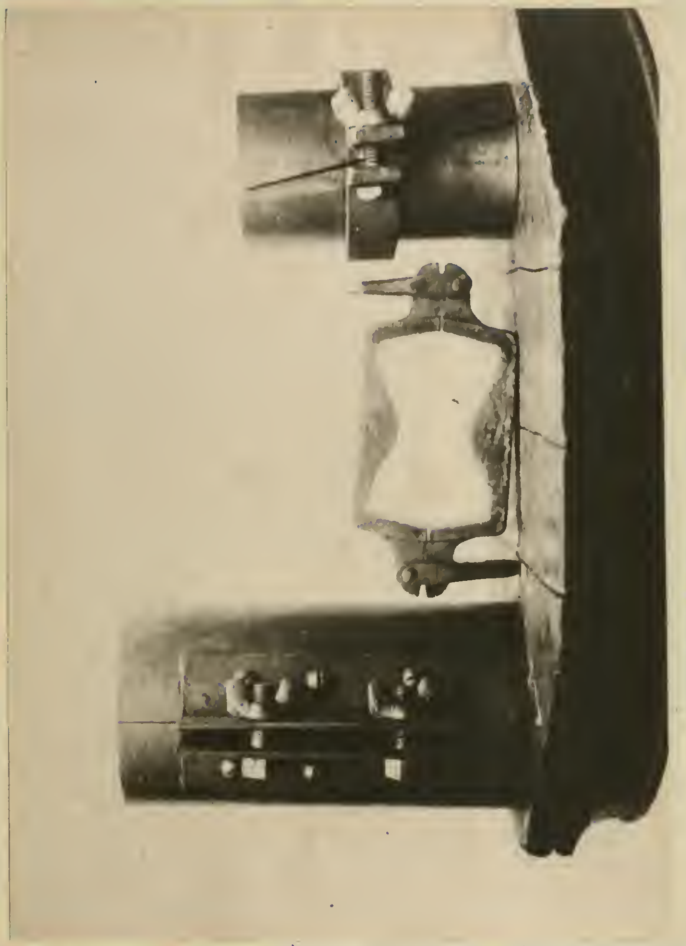
[illegible]

dry mix was shaken through the screen, the sand and cement being thus fairly well mixed. After being shaken through the sieve, the mixture was turned over several times with a trowel until it was of a uniform color throughout.

It was then formed into a heap and a crater made in the center. into this crater was poured the required amount of water. The material was turned into the crater from the edges and a half (1/2) minute allowed for the absorption of the water. It was then thoroughly and vigorously mixed by squeezing with a trowel and by kneading with the hands.

After the batch was thoroughly mixed and of a uniform plasticity throughout, the moulds, shown in Fig. 11, page 7~~2~~3, which had been previously oiled and placed on glass plates covered with waxed paper, were brought forward.

In the preparation of the moulds, a medium grade of cheap engine oil was used. Care was taken to see that the moulds were well oiled so that the specimens could be easily removed. The placing of the moulds on waxed paper prevented, to a great extent, the leaking of water and



MOULDS FOR TEST SPECIMENS.

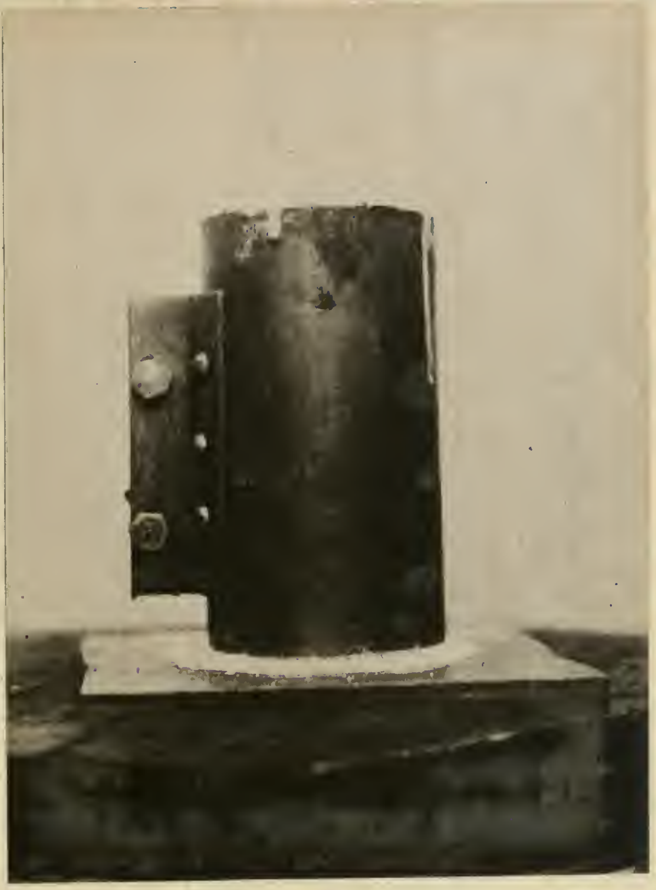
Fig. 11.

cement from the under side of the mould. On page 75 is shown Fig. 12, which illustrates the effect of moulding mortars of wet consistencies without a base of waxed paper. The excess water leaks out from the bottom of the mould carrying with it much of the finer cement particles and forming "laitance", an explanation of which is given in Chapterll.

COMPRESSION SPECIMENS

For the compression teste, five specimens were made for each age of each mortar of each consistency so that a good average result would be obtained. In making up the compression specimens, one 3" x 6" cylinder and four 2"x 4" cylinders were made for each test. A 3" x 6" cylinder was made for each compression group in order to study the effect of increasing the area of section of the test specimen.

In moulding, the cylinder was filled to a depth of about one inch and then lightly tamped. Another inch of mortar was added and tamped. This was done until the mould was full.



LAITANCE DEPOSIT.
DUE TO LEAKAGE FROM MOULD.

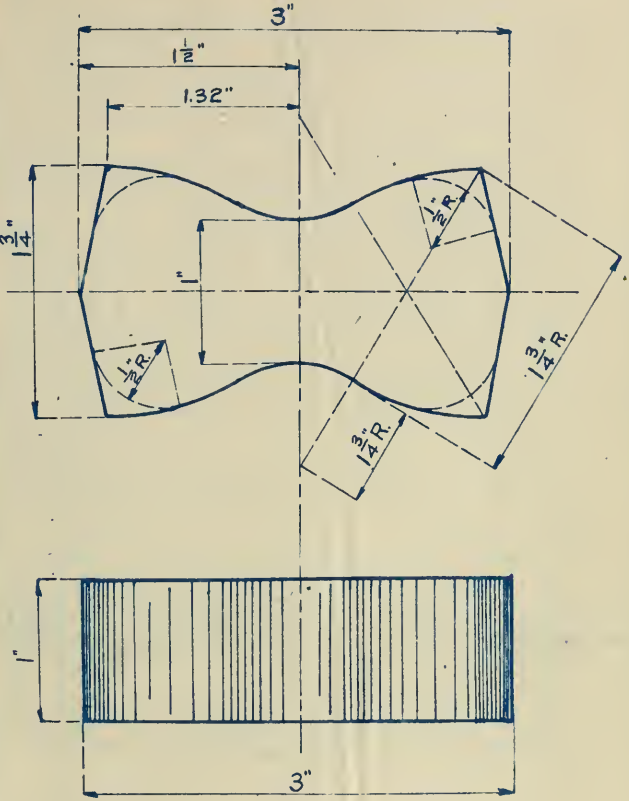
Fig. 12.

Mortar was then heaped on top of the mould and firmly pressed down; then the excess was struck off with a trowel. The moulds were then covered with glass plates and placed in the damp closet for 24 hours.

TENSION SPECIMENS

The tension briquette moulds used, turned out a standard tension briquette which conformed to the standards of the American Society for Testing Materials as shown in Fig. 13, page 77.

The briquette moulds were filled to about half their depth and the mortar firmly pressed in with the fingers. Mortar was heaped on the mould, firmly pressed in with the trowel, and the excess struck off. The moulds were then covered with glass plates and placed in the damp closet.



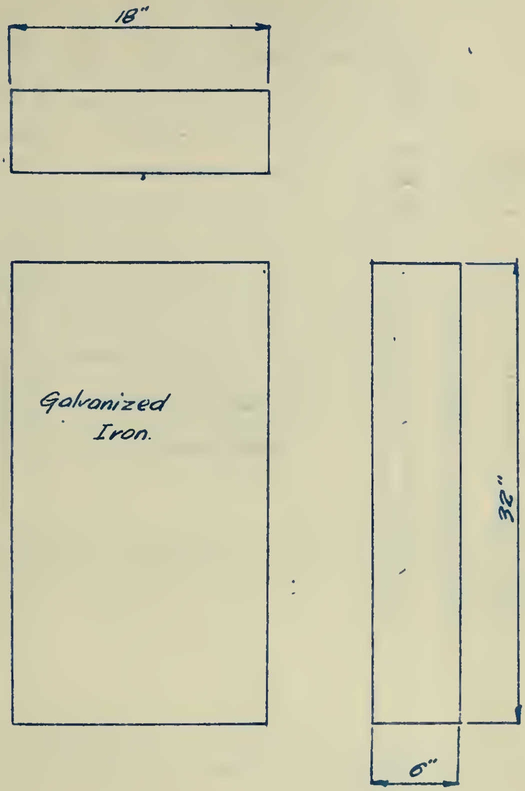
STANDARD BRIQUETTE

Fig. 13

CURING

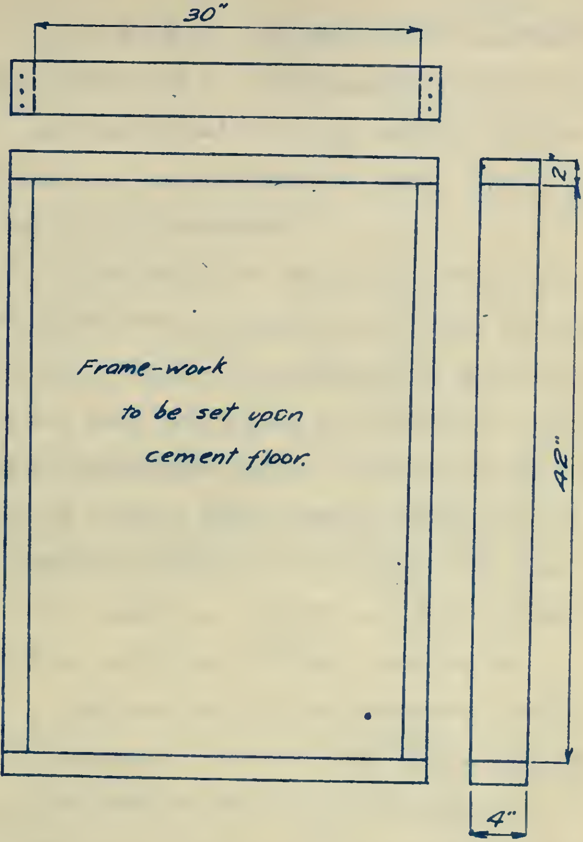
Immediately after moulding, the specimens were placed in the damp closet shown in Fig. 14, page 79. All specimens moulded from the same batch were placed on the same shelf of the damp closet. one shelf in the damp closet was reserved for each batch of mortar. On the same shelf with each batch was placed a tag carrying the batch number. A history of the batch, bearing the same number, was kept on a single sheet of the laboratory notebook.

The specimens were allowed to remain in the damp closet for 24 hours and were then removed from the moulds, marked, and stored in the water storage basins shown in Fig. 15, page 80, for seven days. After seven days, the 28 and 90 day test specimens were removed from the water basins and placed in the damp sand storage boxes shown in Fig. 16, page 81. They were kept in damp sand storage until tested.



Water Storage Basins.

Fig. 15



Sand Storage Boxes.

Fig. 16

MARKING

In work of this kind there is generally a great temptation to introduce an elaborate system of marking containing code numbers or figures which give an insight into the age, proportion, and etc. of the specimen.

This practice is all very well for a series of experiments embracing several thousand test pieces, but where approximately a thousand pieces are used the writer believes such a system to be cumbersome rather than efficient. Many numbers on a small test specimen such as a standard tension briquette, are difficult to place and a large number of figures may readily cause errors when entering them in a note-book.

In this seies of experiments a consecutive system of numbering was used. The numbers of the batches containing the specimens for the 7, 28, and 90 day tests were varied by threes as the batches were placed on the shelves of the damp closet. That is: The batches were numbered 1, 4, 7, 10, 13, and etc. When the batches were removed from the damp closet they were split into

[illegible]

[illegible]

[illegible]

[illegible]

three groups, The seven day group was marked with the number of the batch and the twenty-eight day and ninety day groups were given the next two consecutive numbers respectively.

Thus batch 1 became Groups 1, 2, and 3; batch 7 became Groups 7, 8, and 9. All pieces in the same group, whether for tension or compression tests were given the same serial number.

Each serial number was set down in the laboratory note-book and a complete record of all similarly numbered specimens kept on the same sheet. All marking was done with red marking crayon of the kind known to surveyors and lumberment as "kiel".

CAPPING

When ready for testing, the specimens were removed from storage and allowed to dry for about two hours, before the compression specimens were tested they were capped with Plaster of Paris in the following manner:

A glass plate was well oiled and Plaster

of Paris of a liquid consistency spread over the surface of the plate in a thin layer. The cylinders of cement mortar were then pressed well into the Plaster of Paris and allowed to remain until the plaster was hard. Upon breaking the layer of plaster and removing the cylinders, each cylinder came away with a thingcoating of Plaster of Paris. It was found well to have the cylinders a bit damp when introducing them to the plaster. However, if they are too wet, the plaster will not stick. Both ends of the cylinders were capped.

The reasons for capping with Plaster of Paris are as follows:

1. The rough surface of the cylinder is made smooth.

2. The Plaster of Paris, being softer than the cement mortar, breaks up when pressure is applied and fills up the small openings and irregularities in the surface, thus allowing the pressure to be distributed more uniformly over the surface of the piece.

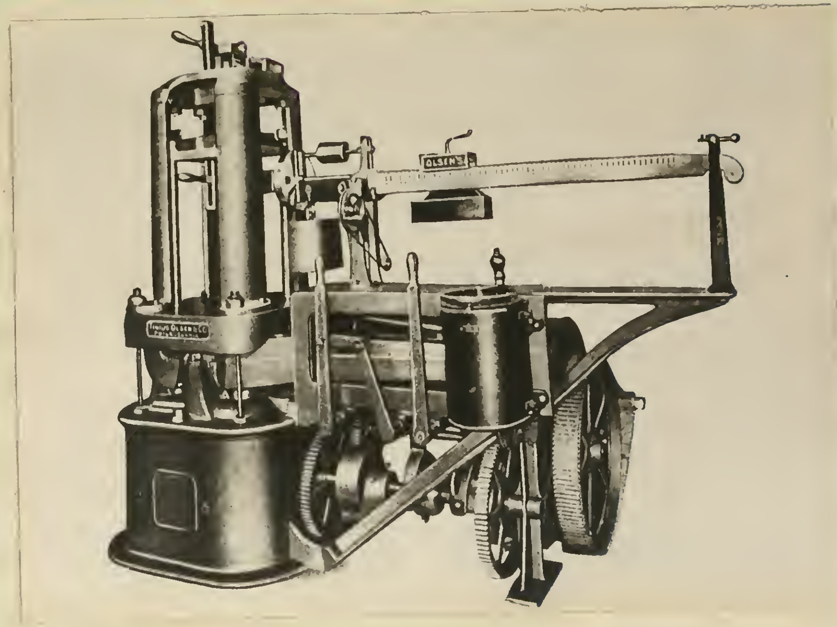
3. The Plaster of Paris, because it is softer than the mortar, acts as a cushion and

tends to prevent shock when the moving head of the testing machine comes in contact with the specimen.

COMPRESSION TESTS

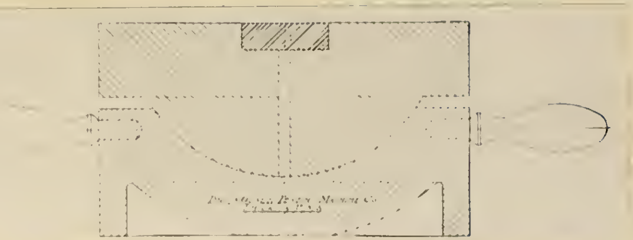
All compression tests were made on the 60,000 Llb. Olsen testing machine shown in Fig. 17, page 86. A solid cylindrical metal block, 6" in diameter and 4" deep, was placed on the weighing table of the machine, and on top of this were placed two smaller blocks, 4" in diameter and 1" deep, with smooth plane contact surfaces, thus providing a solid base for the test piece.

In the center of the moving head of the testing machine was fixed the bearing block shown in Fig. 18, page 87. By means of this block, the load is more evenly distributed over the surface of the specimen. By virtue of the ball and socket arrangement,mthe surface of pressure becomes automatically adjusted to the angle of the surface of the test piece, thus assuring a more even distribution of load over the surface of the test piece in case the surface is not truly



COMPRESSION TESTING MACHINE

Fig. 17



BEARING BLOCK.

Fig. 18.

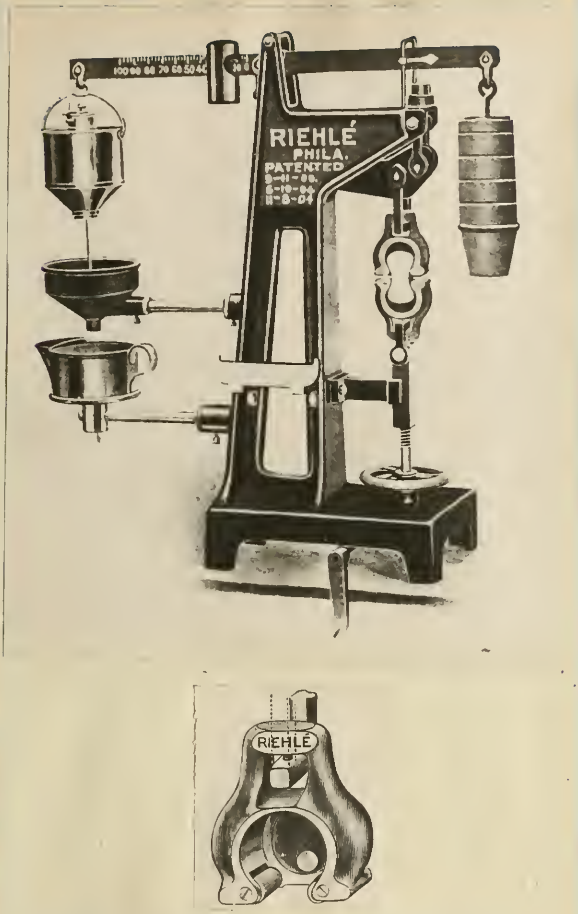
horizontal.

Pressure was applied at the rate of about   Llbs. per minute.

TENSION TESTS

The tests on tension specimens were made on the Riehle tension testing machine shown in Fig. 19, page 89. Care was taken to see that all briquettes were evenly placed in the clips before any load was applied.

Load was applied at the rate of about 600 Llbs per minute.



TENSION TESTING MACHINERY.

CHAPTER V

RESULTS OF FINAL TESTS

LABORATORY DATA

The original laboratory notes consisted only of the following items:

1. Breaking Strength of Briquettes, in Llbs per sq. inch.
2. Breaking Strength of 2" x 4" cylinders, in Llbs.
3. Breaking Strength of 3" x 6" Cylinders, in Llbs.

These figures were later expanded into the following items:

4. Breaking Strength of 2" x 4" Cylinders, in Llbs. per sq. inch.
5. Breaking Strength of 3" x 6" Cylinders, in Llbs. per sq. inch.
6. Average Breaking Strength for Group of Briquettes, in Llbs. per sq. inch.
7. Average Breaking Strength for Group of Cylinders, in Llbs. per sq. inch.

In compiling the results of the tests the breaking strengths of the five tension or compression specimens for each groups were aver-

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[illegible]

[illegible]

aged in order to arrive at an average strength, in Llbs. per sq. inch, for the group. A variation from the average of fifteen percent was allowed. ANY RESULT THAT FELL FIFTEEN PERCENT ABOVE OR BELOW THE AVERAGE FOR THE GROUP WAS REJECTED and the average recorded was the new figure obtained by reaveraging those results which fell within the limit of variation.

The above is, of course, the only logical method of arriving at any definite result. If all specimens were averaged irrespective of their variation from the permissible limit, some pieces which may have been imperfect, would be liable to throw the final result off so far as to lead to the deduction of erronious conclusions.

Those results which were rejected are indicated in the laboratory notes by an asterisk placed in front of the figure.

LABORATORY DATA

LABORATORY DATA

80 Per-Cent Normal Consistency NEAT Mortar

Made Tested

		TENSION	AV. TENS	COMPRESS. 2x4" CYL.		COMPRESS. 3x6" CYL.		AV. COMP
		Lbs./sq in	Lbs./sq in	Lbs.	Lbs sq in	Lbs.	Lbs/sq in	Lbs/sq in
SPECIMEN NO. 1.	AGE 7 DAYS	380		7560	2460			
		365		10340	3280			
		360		8400	2670			
		345		9600	3030			
		370	365			21560	3040	2890

		TENSION	AV. TENS.	COMPRESS 2x4" CYL		COMPRESS 3x6" CYL		AV. COMP.
		Lbs./sq in	Lbs. sq in	Lbs.	Lbs./sq in.	Lbs	Lbs/sq. in.	Lbs/sq. in
SPECIMEN NO. 2.	AGE 28 DAYS	410		9390	3000			
		365		8300	2640			
		480		9520	3030			
		510		10590	3370			
		505	455			21380	3100	3030

		TENSION	AV. TENS.	COMPRESS. 2x4" CYL.		COMPRESS. 3x6 CYL.		AV. COMP
		Lbs. sq in	Lbs. sq in.	Lbs	Lbs. sq in	Lbs.	Lbs./sq in.	Lbs./sq. in.
SPECIMEN NO. 3.	AGE 90 DAYS	530		12230	3900			
		480		11270	3580			
		495		13820	4410			
		545		12960	4130			
		500	510			28450	4020	4010

*Disregarded in figuring average.

LABORATORY DATA

90 Per-Cent Normal Consistency NEAT Mortar

Made Tested

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs/sq in.	Lbs/sq.in.	Lbs.	Lbs/sq.in	Lbs.	Lbs./sq.in.	Lbs/sq.in
SPECIMEN NO. 4.	AGE 7 DAYS	555		13700	4350			
		540		14920	4580			
		510		14630	4650			
		465		13750	4380			
		480	510			34290	4850	4560

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs/sq in.	Lbs/sq in.	Lbs	Lbs/sq in	Lbs.	Lbs/sq in.	Lbs/sq in.
SPECIMEN NO. 5.	AGE 28 DAYS	520		16980	5400			
		540		13200	4200			
		630		15410	4900			
		570		14650	4670			
		555	565			32780	4630	4760

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs./sq.in.	Lbs/sq in.	Lbs.	Lbs./sq.in.	Lbs.	Lbs/sq.in.	Lbs/sq.in.
SPECIMEN NO 6.	AGE 90 DAYS	650		16880	5370			
		*750		17300	5500			
		615		*22800	*7250			
		570		16510	5250			
		605	610			35130	4960	5270

* Disregarded in figuring average.

LABORATORY DATA

100 Per-Cent Normal Consistency NEAT Mortar

Made Tested

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs./sq.in.	Llbs./sq.in.	Llbs	Llbs./sq.in.	Llbs.	Llbs./sq.in.	Llbs./sq.in.
SPECIMEN NO. 7.	AGE 7 DAYS	460		14140	4490			
		*535		13630	4340			
		485		13950	4440			
		410		13320	4250			
		430	445			34050	4820	4470

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs./sq.in.	Llbs./sq.in.	Llbs.	Llbs./sq.in.	Llbs.	Llbs./sq.in.	Llbs./sq.in.
SPECIMEN NO. 8.	AGE 28 DAYS	570		17210	5500			
		595		14990	4760			
		530		16320	5200			
		560		15360	4900			
		515	555			30790	4350	4940

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs./sq.in.	Llbs./sq.in.	Llbs.	Llbs./sq.in.	Llbs.	Llbs./sq.in.	Llbs./sq.in.
SPECIMEN NO. 9	AGE 90 DAYS	680		17660	5600			
		725		23400	7450			
		605		21260	6760			
		730		22790	7300			
		640	680			40720	5750	6570

* Disregarded in figuring average.

LABORATORY DATA

110 Per-Cent Normal Consistency NEAT Mortar

Mode Tested

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs/sq.in	Llbs./sq.in.	Llbs.	Llbs/sq.m.	Llbs.	Llbs/sq.in.	Llbs./sq.in.
SPECIMEN NO. 10.	AGE 7 DAYS	430		12600	4010			
		500		12750	4050			
		415		11590	3680			
		530		13330	4250			
		440	465			30560	4310	4060

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs/sq.in	Llbs/sq in	Llbs.	Llbs/sq in	Llbs.	Llbs/sq in.	Llbs/sq.in.
SPECIMEN NO. 11.	AGE 28 DAYS	560		13820	4400			
		500		15220	4850			
		485		12000	3810			
		570		13410	4270			
		515	520			32340	4560	4380

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs/sq in	Llbs/sq in.	Llbs	Llbs/sq in	Llbs.	Llbs/sq in	Llbs/sq in
SPECIMEN NO. 12.	AGE 90 DAYS	485		17220	5470			
		445		19680	6250			
		495		17700	5640			
		*615		19360	6150			
		460	470			43390	6130	5930

* Disregarded in figuring average.

LABORATORY DATA

120 Per-Cent Normal Consistency NEAT Mortar

Made Tested

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS 3"x6" CYL.		AV. COMP.
		Lbs./sq.in.	Lbs/sq in	Lbs	Lbs./sq.in.	Lbs.	Lbs/sq in	Lbs/sq in
SPECIMEN NO. 13.	AGE 7 DAYS	410		11780	3740			
		375		10540	3360			
		365		11710	3730			
		395		11400	3630			
		380	385			26960	3810	3660

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs/sq in	Lbs/sq in	Lbs	Lbs./sq.in.	Lbs.	Lbs./sq in	Lbs/sq in
SPECIMEN NO. 14.	AGE 28 DAYS	440		12355	3930			
		460		9740	3100			
		490		*13720	*4370			
		495		11000	3500			
		445	465			22900	3240	3730

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs/sq in	Lbs/sq in	Lbs.	Lbs/sq.in.	Lbs.	Lbs/sq in.	Lbs/sq.in
SPECIMEN NO. 15.	AGE 90 DAYS	535		18990	6040			
		620		14730	4680			
		550		16000	5100			
		595		17470	5560			
		505	560			40620	5740	5420

* Disregarded in figuring average.

LABORATORY DATA

130 Per-Cent Normal Consistency NEAT Mortar

Made Tested

		TENSION	AV. TENS	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV COMP.
		Lbs/sq.in	Lbs./sq.in	Lbs.	Lbs/sq in	Lbs.	Lbs/sq.in.	Lbs/sq in
SPECIMEN NO.16	AGE 7 DAYS	300		10130	3230			
		315		11360	3620			
		*395		10500	3340			
		290		10990	3490			
		340	310			24170	3410	3420

		TENSION	AV. TENS	COMPRESS. 2"x4" CYL		COMPRESS 3"x6" CYL		AV. COMP.
		Lbs/sq in	Lbs/sq in	Lbs.	Lbs/sq in	Lbs.	Lbs/sq.in.	Lbs/sq in.
SPECIMEN NO. 17.	AGE 28 DAYS	*540		10720	3410			
		435		12990	4130			
		*315		11340	3620			
		455		11550	3680			
		420	435			21330	3010	3570

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS 3"x6" CYL.		AV. COMP.
		Lbs/sq.in	Lbs/sq in.	Lbs	Lbs./sq in	Lbs.	Lbs./sq.in.	Lbs/sq.in.
SPECIMEN NO. 18.	AGE 90 DAYS	435		17250	5500			
		465		*20380	*6490			
		530		16300	5190			
		405		15150	4830			
		345	460			31210	4420	4990

*Disregarded in figuring average.

LABORATORY DATA

140 Per-Cent Normal Consistency NEAT Mortar

Made Tested

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs/sq.in.	Llbs/sq.in.	Llbs.	Llbs./sq.in.	Llbs.	Llbs./sq.in.	Llbs/sq.in
SPECIMEN NO. 19	AGE 7 DAYS	320		10310	3280			
		310		9670	3080			
		280		10060	3200			
		315		8460	2700			
		295	305			23350	3300	3110

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs/sq in.	Llbs/sq in.	Llbs	Llbs/sq.in	Llbs.	Llbs, sq in.	Lbs/sq in
SPECIMEN NO. 20	AGE 28 DAYS	430		10930	3470			
		*510		9450	3000			
		*295		10790	3430			
		330		9870	3120			
		*300	380			26090	3680	3340

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs./sq in.	Llbs/sq in.	Llbs	Llbs./sq.in.	Llbs.	Llbs./sq in.	Llbs./sq.in.
SPECIMEN NO. 21	AGE 90 DAYS	350		*20560	*6530			
		360		14600	4650			
		435		15200	4850			
		430		15890	5050			
		485	410			33170	4680	4810

* Disregarded in figuring average.

LABORATORY DATA

80 Per-Cent Normal Consistency 1—1 Mortar

Made Tested

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs./sq. in.	Lbs./sq. in.	Lbs	Lbs./sq. in.	Lbs	Lbs/sq. in.	Lbs./sq. in.
SPECIMEN NO. 22.	AGE 7 DAYS	305		6490	2060			
		290		6530	2080			
		340		*8010	2550			
		280		7110	2260			
		340	310			14430	2040	2110

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs./sq. in.	Lbs./sq. in.	Lbs.	Lbs./sq. in.	Lbs.	Lbs./sq. in.	Lbs./sq. in.
SPECIMEN NO. 23.	AGE 28 DAYS	325		7210	2300			
		315		6580	2090			
		365		6720	2140			
		335		7460	2380			
		315	330			18240	2580	2300

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs./sq. in.	Lbs./sq. in.	Lbs.	Lbs./sq. in.	Lbs.	Lbs./sq. in.	Lbs./sq. in.
SPECIMEN NO. 24.	AGE 90 DAYS	* 435		14000	4460			
		* 270		12260	3900			
		340		11880	3780			
		400		12240	3900			
		290	345			29400	4160	4040

* Disregarded in figuring average.

LABORATORY DATA

90 Per-Cent Normal Consistency 1—1 Mortar

Made Tested

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs./sq.in.	Lbs./sq.in.	Lbs.	Lbs./sq.in.	Lbs.	Lbs./sq.in.	Lbs./sq.in.
SPECIMEN NO. 25.	AGE 7 DAYS	420		12900	4100			
		465		12370	3910			
		350		10430	3310			
		400		11760	3740			
		390	405			29850	4220	3860

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs./sq.in.	Lbs./sq.in.	Lbs.	Lbs./sq.in.	Lbs.	Lbs./sq.in.	Lbs./sq.in.
SPECIMEN NO. 26.	AGE 28 DAYS	340		12980	4120			
		495		11160	3550			
		455		12320	3920			
		515		11210	3580			
		480	465			30640	4350	3900

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs./sq.in.	Lbs./sq.in.	Lbs.	Lbs./sq.in.	Lbs.	Lbs./sq.in.	Lbs./sq.in.
SPECIMEN NO. 27.	AGE 90 DAYS	470		16270	5170			
		*410		15940	5070			
		475		*11460	*3640			
		515		14320	4560			
		490	560			38450	5440	5060

* Disregarded in figuring average.

LABORATORY DATA

100 Per-Cent Normal Consistency 1—1 Mortar

Made Tested

		TENSION	AV. TENS.	COMPRESS 2"x4" CYL		COMPRESS 3"x6" CYL		AV. COMP.
		Llbs./sq.in.	Llbs/sq in	Llbs	Llbs./sq in	Llbs	Llbs/sq in	Llbs./sq in
SPECIMEN NO. 28.	AGE 7 DAYS	375		11540	3860			
		370		10090	3200			
		335		10660	3380			
		340		11110	3540			
		360	355			24260	3430	3450

		TENSION	AV. TENS.	COMPRESS 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs/sq in	Llbs/sq in	Llbs.	Llbs./sq.in.	Llbs.	Llbs./sq in	Llbs/sq in
SPECIMEN NO. 29.	AGE 28 DAYS	530		13600	4330			
		460		12750	4050			
		480		14300	4550			
		570		13780	4390			
		485	505			33920	4800	4420

		TENSION	AV TENS.	COMPRESS 2"x4" CYL.		COMPRESS. 3"x6" CYL		AV COMP.
		Llbs/sq.in.	Llbs/sq in	Llbs.	Llbs/sq.in	Llbs.	Llbs./sq.in.	Llbs/sq.in
SPECIMEN NO. 30.	AGE 90 DAYS	*440		20000	6350			
		530		19240	6120			
		620		*22710	*7220			
		590		19600	6240			
		510	565			37410	5300	6000

* Disregarded in figuring average.

LABORATORY DATA

110 Per-Cent Normal Consistency 1—1 Mortar

Made Tested

SPECIMEN NO. 31.	AGE 7 DAYS	TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs./sq. in.	Lbs./sq. in.	Lbs.	Lbs./sq. in.	Lbs.	Lbs./sq. in.	Lbs./sq. in.
		*400		9050	2880			
		345		7500	2390			
		295		7030	2240			
		335		7390	2350			
		305	320			*21490	3040	2470

SPECIMEN NO. 32.	AGE 28 DAYS	TENSION	AV. TENS.	COMPRESS 2"x4" CYL		COMPRESS 3"x6" CYL		AV. COMP.
		Lbs./sq. in.	Lbs./sq. in.	Lbs.	Lbs./sq. in.	Lbs.	Lbs./sq. in.	Lbs./sq. in.
		470		11620	3700			
		515		12510	3980			
		500		*8850	2820			
		480		11330	3600			
		520	500			*32570	*4600	3760

SPECIMEN NO. 33.	AGE 90 DAYS	TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS 3"x6" CYL.		AV. COMP.
		Lbs./sq. in.	Lbs./sq. in.	Lbs.	Lbs./sq. in.	Lbs.	Lbs./sq. in.	Lbs./sq. in.
		510		18780	5970			
		645		17310	5500			
		610		18390	5850			
		595		17730	5650			
		540	580			37190	5250	5640

*Disregarded in figuring average.

LABORATORY DATA

120 Per-Cent Normal Consistency 1-1 Mortar

Made Tested

		TENSION	Av. TENS.	COMPRESS. 2"x4" CYL		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs/sq.in.	Llbs/sq.in.	Llbs.	Llbs/sq.in	Llbs.	Llbs./sq in.	Llbs/sq.in
SPECIMEN NO. 34.	AGE 7 DAYS	*375		5020	1600			
		350		7370	2250			
		310		5890	1880			
		300		5420	1730			
		290	310			15140	2140	1920.

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs/sq.in.	Llbs/sq in.	Llbs.	Llbs/sq.in.	Llbs.	Llbs/sq. in.	Lbs/sq in.
SPECIMEN NO. 35.	AGE 28 DAYS	510		*14910	*4750			
		420		11030	3510			
		485		11465	3640			
		425		*8350	*2920			
		440	450			26510	3740	3630

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs./sq.in.	Llbs/sq. in.	Llbs.	Llbs./sq. in.	Llbs.	Llbs./sq.in	Llbs./sq.in.
SPECIMEN NO. 36.	AGE 90 DAYS	540		18310	5830			
		510		16500	5250			
		490		16090	5110			
		540		17200	5470			
		470	510			40740	5750	5480

* Disregarded in figuring average.

LABORATORY DATA

130 Per-Cent Normal Consistency 1-1 Mortar

Made Tested

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs./sq. in.	Lbs./sq. in.	Lbs.	Lbs./sq. in.	Lbs.	Lbs./sq. in.	Lbs./sq. in.
SPECIMEN NO. 37.	AGE 7 DAYS	295		5970	1900			
		265		6000	1910			
		285		6180	1970			
		305		6090	1940			
		260	280			14270	2020	1950

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs./sq. in.	Lbs./sq. in.	Lbs.	Lbs./sq. in.	Lbs.	Lbs./sq. in.	Lbs./sq. in.
SPECIMEN NO. 38.	AGE 28 DAYS	460		12030	3830			
		430		10360	3300			
		470		11720	3720			
		415		11380	3620			
		430	440			23100	3260	3550

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs./sq. in.	Lbs./sq. in.	Lbs.	Lbs./sq. in.	Lbs.	Lbs./sq. in.	Lbs./sq. in.
SPECIMEN NO. 39.	AGE 90 DAYS	485		16020	5090			
		480		18680	5940			
		535		17310	5500			
		440		16590	5270			
		465	480			34070	4800	5320

* Disregarded in figuring average.

LABORATORY DATA

·140 Per-Cent Normal Consistency 1—1 Mortar

Made Tested

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs/sq.in	Llbs./sq.in.	Llbs.	Llbs/sq.in.	Llbs.	Llbs./sq.in.	Llbs./sq.in.
SPECIMEN NO. 40.	AGE 7 DAYS	250		4190	1330			
		245		4570	1450			
		255		4730	1500			
		235		4350	1390			
		240	245			11580	1640	1460

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs/sq.in	Llbs/sq in	Llbs.	Llbs./sq.in	Llbs.	Llbs./sq.in.	Llbs/sq.in.
SPECIMEN NO. 41.	AGE 28 DAYS	390		9890	3140			
		420		10970	3490			
		400		9610	3060			
		410		9380	2980			
		380	400			25750	3640	3260

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs/sq.in.	Llbs/sq.in.	Llbs	Llbs/sq.in	Llbs.	Llbs/sq.in	Llbs/sq.in
SPECIMEN NO. 42.	AGE 90 DAYS	420		16400	5210			
		410		16460	5240			
		495		15610	4970			
		485		14960	4750			
		390	440			32240	4560	4950

* Disregarded in figuring average.

LABORATORY DATA

80 Per-Cent Normal Consistency 1—2 Mortar

Made Tested

		TENSION	AV. TENS.	COMPRESS 2"x4" CYL.		COMPRESS 3"x6" CYL.		AV. COMP.
		Lbs./sq. in.	Lbs./sq. in	Lbs	Lbs./sq. in.	Lbs.	Lbs./sq. in	Lbs./sq. in
SPECIMEN NO. 43.	AGE 7 DAYS	140		3550	1130			
		150		3610	1150			
		155		*5350	1700			
		175		4030	1280			
		165	160			6860	970	1130

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs./sq. in	Lbs./sq. in	Lbs.	Lbs./sq. in.	Lbs.	Lbs./sq. in	Lbs./sq. in
SPECIMEN NO. 44.	AGE 28 DAYS	175		3990	1270			
		165		4260	1360			
		*200		3880	1240			
		155		3910	1250			
		160	165			9980	1410	1310

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs./sq. in	Lbs./sq. in	Lbs.	Lbs./sq. in.	Lbs	Lbs./sq. in.	Lbs./sq. in
SPECIMEN NO. 45.	AGE 90 DAYS	200		5920	1880			
		195		6330	2010			
		*265		5670	1800			
		230		4960	1580			
		180	175			13610	1930	1840

* Disregarded in figuring average.

LABORATORY DATA

90 Per-Cent Normal Consistency 1—2 Mortar

Made Tested

		TENSION	AV. TENS	COMPRESS. 2"x4" CYL.		COMPRESS. 3x6" CYL.		AV. COMP.
		Lbs./sq in	Lbs./sq in.	Lbs.	Lbs/sq in	Lbs.	Lbs/sq in.	Lbs/sq in
SPECIMEN NO. 46.	AGE 7 DAYS	165		3770	1200			
		185		4080	1300			
		195		4000	1270			
		165		3640	1160			
		*230	175			*14350	*2030	1230

		TENSION	AV. TENS.	COMPRESS 2x4" CYL		COMPRESS 3x6" CYL		AV COMP.
		Lbs./sq in.	Lbs./sq in	Lbs.	Lbs./sq in	Lbs.	Lbs./sq. in.	Lbs./sq. in.
SPECIMEN NO. 47.	AGE 28 DAYS	250		6870	2180			
		270		6410	2040			
		305		6720	2140			
		255		6000	1910			
		265	270			13750	1940	2040

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS 3"x6" CYL.		AV. COMP
		Lbs./sq in.	Lbs./sq in.	Lbs	Lbs./sq in.	Lbs.	Lbs./sq. in.	Lbs./sq in.
SPECIMEN NO. 48.	AGE 90 DAYS	270		*10080	*3200			
		*375		*6190	*1970			
		330		7390	2950			
		*205		7130	2270			
		260	285			*23850	*3380	2910

*Disregarded in figuring average.

LABORATORY DATA

100 Per-Cent Normal Consistency 1-2 Mortar

Made Tested

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3x6 CYL.		AV. COMP.
		Lbs/sq. in	Lbs/sq. in.	Lbs.	Lbs./sq. in	Lbs.	Lbs./sq. in.	Lbs/sq in
SPECIMEN NO. 49.	AGE 7 DAYS.	280		4890	1560			
		295		4190	1330			
		320		4660	1480			
		295		4545	1450			
		270	290			*14150	*2000	1460

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs/sq in	Lbs/sq in.	Lbs	Lbs/sq in.	Lbs.	Lbs./sq in.	Lbs/sq in.
SPECIMEN NO 50	AGE 28 DAYS	340		9360	2980			
		305		8690	2760			
		310		7600	2420			
		270		8150	2590			
		305	305			19010	2690	2690

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL		COMPRESS. 3"x6" CYL.		AV COMP.
		Lbs./sq in.	Lbs/sq in.	Lbs.	Lbs./sq. in.	Lbs.	Lbs./sq in	Lbs./sq. in
SPECIMEN NO 51	AGE 90 DAYS	435		8270	2630			
		450		9260	2940			
		395		10140	3230			
		435		9090	2890			
		460	435			*26580	*3760	2920

* Disregarded in figuring average.

LABORATORY DATA

110 Per-Cent Normal Consistency 1-2 Mortar

Made Tested

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs./sq. in.	Llbs./sq. in.	Llbs.	Llbs./sq. in.	Llbs.	Llbs./sq. in.	Llbs./sq. in.
SPECIMEN NO. 52	AGE 7 DAYS	290		5250	1670			
		225		5040	1600			
		285		4330	1380			
		230		4700	1500			
		275	260			12090	1710	1570

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs./sq. in.	Llbs./sq. in.	Llbs.	Llbs./sq. in.	Llbs.	Llbs./sq. in.	Llbs./sq. in.
SPECIMEN NO. 53	AGE 28 DAYS	355		7940	2520			
		380		8850	2820			
		415		*11230	*3580			
		370		7790	2480			
		390	380			22400	3240	2760

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs./sq. in.	Llbs./sq. in.	Llbs.	Llbs./sq. in.	Llbs.	Llbs./sq. in.	Llbs./sq. in.
SPECIMEN NO. 54	AGE 90 DAYS	* 340		14030	4450			
		495		*17270	*5470			
		460		*11140	*3540			
		510		13160	4180			
		470	485			32450	4590	4070

* Disregarded in figuring average.

LABORATORY DATA

120 Per-Cent Normal Consistency 1–2 Mortar

Made Tested

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs/sq in.	Lbs./sq in.	Lbs.	Lbs/sq in.	Lbs.	Lbs/sq. in.	Lbs./sq. in.
SPECIMEN NO. 55.	AGE 7 DAYS	230		3730	1190			
		255		3710	1180			
		225		3910	1250			
		265		4010	1280			
		235	240			9750	1380	1260

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs/sq in	Lbs/sq in	Lbs.	Lbs/sq in.	Lbs.	Lbs./sq in.	Lbs/sq in.
SPECIMEN NO. 56.	AGE 28 DAYS	*395		*9510	*3020			
		335		7300	2320			
		285		8670	2760			
		295		7660	2440			
		320	310			20000	2830	2590

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs/sq in	Lbs/sq in.	Lbs	Lbs/sq in	Lbs.	Lbs/sq in	Lbs/sq. in
SPECIMEN NO. 57.	AGE 90 DAYS	526		16700	5320			
		570		14030	4450			
		580		15570	4950			
		560		15290	4860			
		530	550			33310	4710	4860

* Disregarded in figuring average.

LABORATORY DATA

130 Per-Cent Normal Consistency	1-2 Mortar
Made	Tested

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS 3"x6" CYL.		AV. COMP.
		Llbs./sq.in.	Llbs./sq in	Llbs	Llbs./sq in	Llbs.	Llbs./sq in	Llbs./sq.in
SPECIMEN NO. 58.	AGE 7 DAYS	185		2970	945			
		145		2710	865			
		205		*2250	716			
		170		2800	890			
		190	190			7010	990	920

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs./sq in.	Llbs./sq in	Llbs.	Llbs./sq.in.	Llbs.	Llbs. sq in	Llbs./sq in
SPECIMEN NO. 59.	AGE 28 DAYS	340		7640	2440			
		230		7770	2470			
		*400		8260	2630			
		320		7420	2360			
		280	290			17300	2450	2470

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs./sq.in.	Llbs./sq in	Llbs.	Llbs./sq.in	Llbs.	Llbs./sq.in.	Llbs./sq in
SPECIMEN NO. 60.	AGE 90 DAYS	490		14850	4730			
		500		16240	5170			
		440		12590	4040			
		430		13620	4340			
		460	465			*27140	*3830	4840

* Disregarded in figuring average.

LABORATORY DATA

140 Per-Cent Normal Consistency 1-2 Mortar

Made Tested

		TENSION	AV. TENS	COMPRESS 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs/sq -	Lbs/sq in	Lbs.	Lbs/sq in	Lbs.	Lbs./sq. in.	Lbs/sq in
SPECIMEN NO. 61.	AGE 7 DAYS	150		2260	720			
		155		2340	745			
		180		2290	730			
		145		2400	765			
		170	160			5120	725	740

		TENSION	AV. TENS.	COMPRESS 2"x4" CYL		COMPRESS 3"x6" CYL		AV. COMP.
		lbs./sq. in.	Lbs./sq in	Lbs.	Lbs/sq in	Lbs.	Lbs./sq. in	Lbs./sq. in.
SPECIMEN NO. 62.	AGE 28 DAYS	260		6950	2210			
		305		8100	2580			
		240		*6000	*1910			
		225		6620	2100			
		230	250			*18770	*2640	2230

		TENSION	AV. TENS.	COMPRESS 2"x4" CYL.		COMPRESS 3"x6" CYL.		AV. COMP
		Lbs/sq. in.	Lbs/sq. in.	Lbs.	Lbs/sq in.	Lbs.	Lbs./sq. in.	Lbs/sq. in.
SPECIMEN NO. 63.	AGE 90 DAYS	*555		12580	4000			
		435		13680	4350			
		450		14210	4520			
		390		12530	3910			
		405	420			31160	4400	4260

*Disregarded in figuring average.

LABORATORY DATA

80 Per-Cent Normal Consistency 1–3 Mortar

Made Tested

SPECIMEN NO. 64
AGE 7 DAYS

TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
Lbs/sq.in.	Lbs/sq.in.	Lbs.	Lbs/sq.in.	Lbs.	Lbs/sq.in.	Lbs/sq.in.
95		*1080	*344			
90		2050	650			
95		1870	595			
80		1920	610			
90	90			*5180	*730	620

SPECIMEN NO. 65.
AGE 28 DAYS

TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
Lbs/sq.in.	Lbs/sq.in.	Lbs.	Lbs/sq.in.	Lbs.	Lbs/sq in.	Lbs/sq in.
125		2520	805			
150		*3830	*1220			
*270		2490	790			
110		2600	825			
140	130			6930	980	850

SPECIMEN NO. 66.
AGE 90 DAYS

TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
Lbs./sq in	Lbs/sq in	Lbs	Lbs./sq.in.	Lbs.	Lbs./sq in.	Lbs./sq in
225		2880	916			
190		3450	1100			
240		3520	1120			
235		3260	1040			
210	220			*9600	*1360	1040

* Disregarded in figuring average.

LABORATORY DATA

90 Per-Cent Normal Consistency 1-3 Mortar

Made Tested

		TENSION	AV TENS.	COMPRESS. 2"x4 CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs./sq in.	Lbs./sq in	Lbs	Lbs./sq in.	Lbs.	Lbs/sq in.	Lbs/sq.in
SPECIMEN NO 67	AGE 7 DAYS	125		3070	977			
		100		2360	750			
		110		2720	865			
		115		2530	805			
		105	110			6650	940	870

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs./sq in.	Lbs./sq in.	Lbs.	Lbs./sq. in.	Lbs.	Lbs./sq in.	Lbs./sq. in.
SPECIMEN NO 68.	AGE 28 DAYS	175		3670	1170			
		170		*2420	*770			
		145		3420	1090			
		150		3360	1070			
		160	160			7620	1080	1100

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL		AV. COMP.
		Lbs./sq. in.	Lbs./sq.in.	Lbs.	Lbs /sq. in.	Lbs.	Lbs./sq in.	Lbs./sq. in.
SPECIMEN NO 69.	AGE 90 DAYS	320		5360	2340			
		*260		5790	2480			
		330		6690	2760			
		290		5940	2520			
		305	310			20730	2930	2610

* Disregarded in figuring average.

LABORATORY DATA

100 Per-Cent Normal Consistency 1-3 Mortar

Made Tested

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs/sq.in	Llbs./sq.in.	Llbs.	Llbs/sq.in.	Llbs.	Llbs/sq.in.	Llbs./sq.in.
SPECIMEN NO. 70.	AGE 7 DAYS	130		2400	765			
		135		2750	876			
		145		2650	845			
		130		2490	796			
		130	135			5620	795	820

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs/sq.in	Llbs/sq in	Llbs.	Llbs./sq.in.	Llbs.	Llbs./sq.in.	Llbs/sq.in.
SPECIMEN NO. 71.	AGE 28 DAYS	170		3980	1270			
		210		*2700	*860			
		205		3150	1000			
		190		3840	1220			
		185	190			9460	1340	1210

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs/sq.in.	Llbs/sq.in.	Llbs.	Llbs/sq.in	Llbs.	Llbs/sq.in	Llbs/sq.in
SPECIMEN NO. 72.	AGE 90 DAYS	300		6760	2150			
		310		5780	1840			
		315		5980	1900			
		345		6370	2030			
		*580	315			*18030	*2550	1980

*Disregarded in figuring average.

LABORATORY DATA

110 Per-Cent Normal Consistency 1—3 Mortar

Made Tested

SPECIMEN NO. 73.	AGE 7 DAYS	TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS 3x6 CYL.		AV. COMP.
		Llbs./sq.in.	Llbs./sq in	Llbs	Llbs./sq in	Llbs.	Llbs./sq in	Llbs./sq in
		130		2000	640			
		125		2240	715			
		110		2120	675			
		115		2370	755			
		110	120			4840	685	640

SPECIMEN NO. 74.	AGE 28 DAYS	TENSION	AV. TENS.	COMPRESS. 2x4 CYL.		COMPRESS. 3x6 CYL.		AV. COMP.
		Llbs./sq in	Llbs./sq in	Llbs	Llbs./sq.in.	Llbs	Llbs./sq in	Llbs/sq in
		260		4390	1400			
		205		4700	1500			
		215		4240	1350			
		250		4570	1460			
		225	230			10750	1520	1450

SPECIMEN NO. 75.	AGE 90 DAYS	TENSION	AV TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs./sq.in.	Llbs/sq in	Llbs.	Llbs/sq in	Llbs.	Llbs./sq in.	Llbs/sq in
		350		6450	2050			
		355		7420	2360			
		325		6970	2220			
		345		7190	2290			
		310	335			16360	2310	2250

* Disregarded in figuring average.

LABORATORY DATA

120 Per-Cent Normal Consistency 1—3 Mortar

Made Tested

SPECIMEN NO. 76.
AGE 7 DAYS

TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
Llbs./sq.in.	Llbs./sq.in.	Llbs.	Llbs./sq.in.	Llbs.	Llbs./sq.in.	Llbs./sq.in.
115		1970	627			
90		*1785	*570			
125		1810	576			
100		*2500	*795			
95	105			*5770	*815	600

SPECIMEN NO. 77.
AGE 28 DAYS

TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
Llbs./sq.in.	Llbs./sq.in.	Llbs.	Llbs./sq.in.	Llbs.	Llbs./sq.in.	Llbs./sq.in.
215		3450	1100			
220		*5350	*1710			
230		3920	1250			
225		3620	1150			
210	220			*11150	* 1580	1160

SPECIMEN NO. 78
AGE 90 DAYS

TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
Llbs/sq.in.	Llbs./sq. in.	Llbs.	Llbs./sq.in.	Llbs.	Llbs./sq.in.	Llbs/sq.in.
395		7830	2490			
365		8200	2610			
380		8150	2590			
360		7950	2530			
320	365			19140	2710	2590

*Disregarded in figuring average.

LABORATORY DATA

130 Per-Cent Normal Consistency 1-3 Mortar

Made Tested

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs./sq.in.	Lbs./sq.in.	Lbs.	Lbs./sq.in.	Lbs.	Lbs./sq.in.	Lbs./sq.in.
SPECIMEN NO. 79	AGE 7 DAYS	130		2180	695	4710	665	
		150		2070	660			
		145		2300	730			
		140		2100	670			
		140	140					684

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs./sq.in.	Lbs./sq.in.	Lbs.	Lbs./sq.in.	Lbs.	Lbs./sq.in.	Lbs./sq.in.
SPECIMEN NO. 80.	AGE 28 DAYS	205		2950	940			
		250		3040	970			
		200		3020	960			
		*125		3330	1060			
		170	205			6470	920	970

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Lbs./sq.in.	Lbs./sq.in.	Lbs.	Lbs./sq.in.	Lbs.	Lbs./sq.in.	Lbs./sq.in.
SPECIMEN NO. 81	AGE 90 DAYS	*460		8210	2610			
		330		*10170	*3230			
		300		8260	2630			
		325		8620	2740			
		315	320			18550	2620	2650

* Disregarded in figuring average.

LABORATORY DATA

140 Per-Cent Normal Consistency 1-3 Mortar

Mode Tested

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs./sq.in.	Llbs./sq.in.	Llbs.	Llbs./sq.in.	Llbs.	Llbs./sq.in.	Llbs./sq.in.
SPECIMEN NO. 82.	AGE 7 DAYS	120		2040	650	650		
		115		1990	635	635		
		110		1630	520	520		
		115		1750	555	556		
		95	110			4530	640	600

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs/sq.in.	Llbs./sq. in.	Llbs.	Llbs/sq.in.	Llbs.	Llbs./sq. in.	Llbs./sq.in.
SPECIMEN NO. 83.	AGE 28 DAYS	215		2900	930			
		160		2630	840			
		*290		2800	890			
		175		2760	880			
		200	185			8920	1180	940

		TENSION	AV. TENS.	COMPRESS. 2"x4" CYL.		COMPRESS. 3"x6" CYL.		AV. COMP.
		Llbs./sq. in.	Llbs./sq.in.	Llbs.	Llbs./sq. in.	Llbs.	Llbs./sq. in.	Llbs./sq. in.
SPECIMEN NO. 84.	AGE 90 DAYS	290		7630	2430			
		*360		*9480	*3020			
		310		7420	2360			
		305		8110	2580			
		275	295			17720	2510	2470

* Disregarded in figuring average.

CURVES

The following curves were plotted in order to show graphically the results of this series of experiments. It must be understood that the curves are not exactly accurate, that is: they are not drawn through all of the plotted points.

It is hardly possible that in such experiments as these, where no great or sudden variations are to be expected, that a single point at a relatively great distance from a smooth curve drawn through all of the other points plotted, is a true point on the curve. It is more likely that such a point is in error, and in work such as this , may be due to any number of causes. It would therefore be unwise to attempt to draw all curves exactly through all points.

Even by so doing, the curve would not be a true representation of the results because of various opportunities for error throughout the experiments. Such an attempt at accuracy would savor somewhat of the story of the surveyor who, in striving for precision, would pace distances and record them in his fieldbook to the third decimal place.

The curves were drawn through all points.

when indications showed such points to be correct. When certain points were considerably off line and conditions seemed to indicate such points as being in error, those points were not considered when the curves were drawn.

All points, however, are located on the graph sheets.

KINDS OF CURVES.

There are two sets of curves included in this work, viz.:

STRENGTH-CONSISTENCY curves, which show the relation between strengths and percentages of normal consistency of different mortars at different ages.

STRENGTH-AGE curves, which show the relation between strength and age of different consistencies of the same mortar.

Each set of curves includes:

Primary curves.
Average curves.
General curves.

PRIMARY CURVES.

The primary curves are what their name implies -- true curves (as true as is compatible with the degree of accuracy maintained throughout these experiments) drawn through points which were plotted directly from the tables of laboratory Data. The maximum number of results averaged to obtain these curves can be no more than five.

AVERAGE CURVES.

In plotting an average curve, each ordinate of the average curve was obtained by taking the average ordinate of all curves on the sheet. Thus for curve 6, containing one curve for each mortar; the ordinates of each curve being the compressive strengths in Llbs. per sq. inch, and the abscissae the percentages of normal consistency, the average curve would be such a curve whose ordinates for each point of percent of normal consistency were the average of the ordinates of all four curves at the same point.

The average curve, therefore, would be a condesation of all four curves and would illustrate the trend of results better than do the primary curves. Detail, however, would be considerably decreased.

Tables for the average curves are included in each set.

GENERAL CURVES

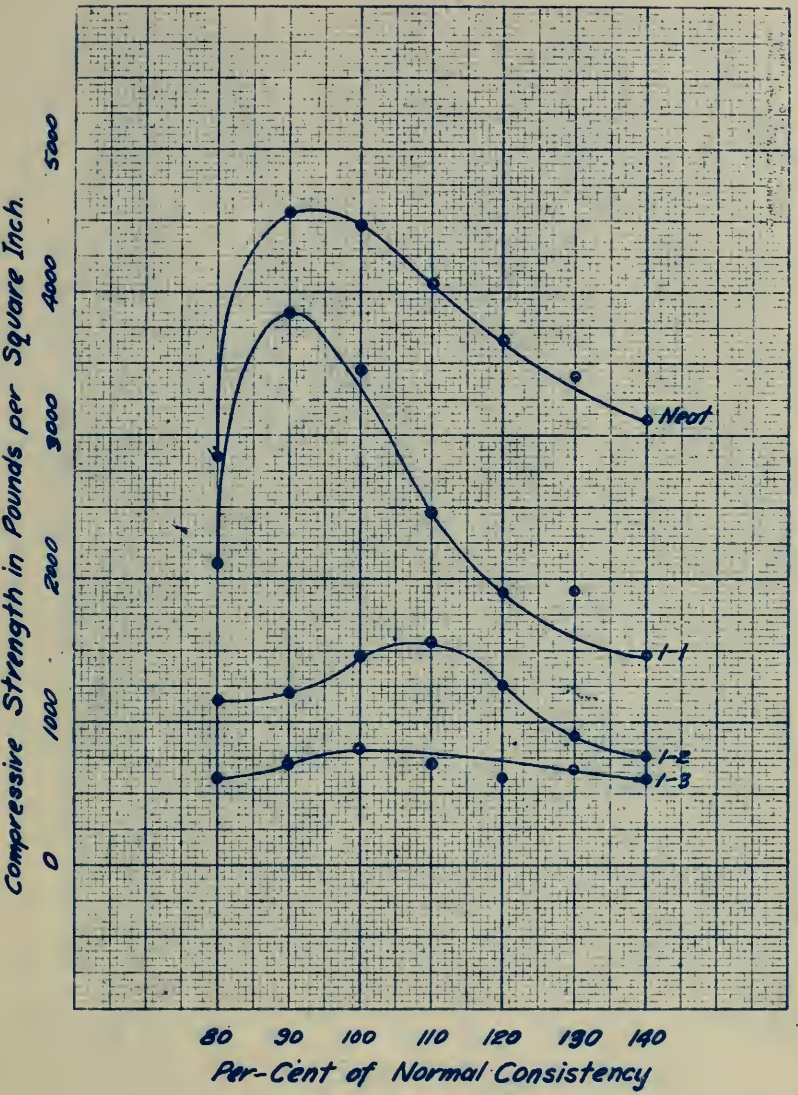
The general curves are a generalization of the average curves. The ordinates of the general curves are the average of the corresponding ordinates of the average curves.

The general curves, while they give very little detail regarding the experiments, serve to illustrate best the general trend of results.

Tables for the general curves are included in each set.

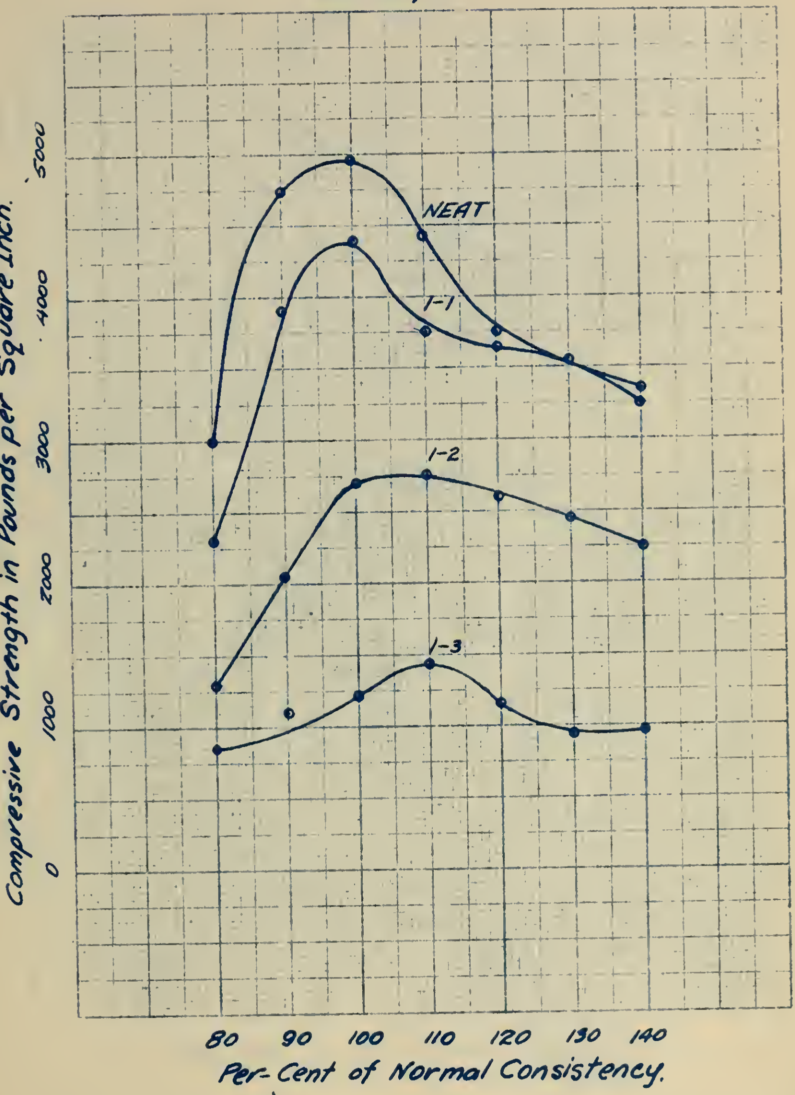
STRENGTH-CONSISTENCY CURVES

7 Days.

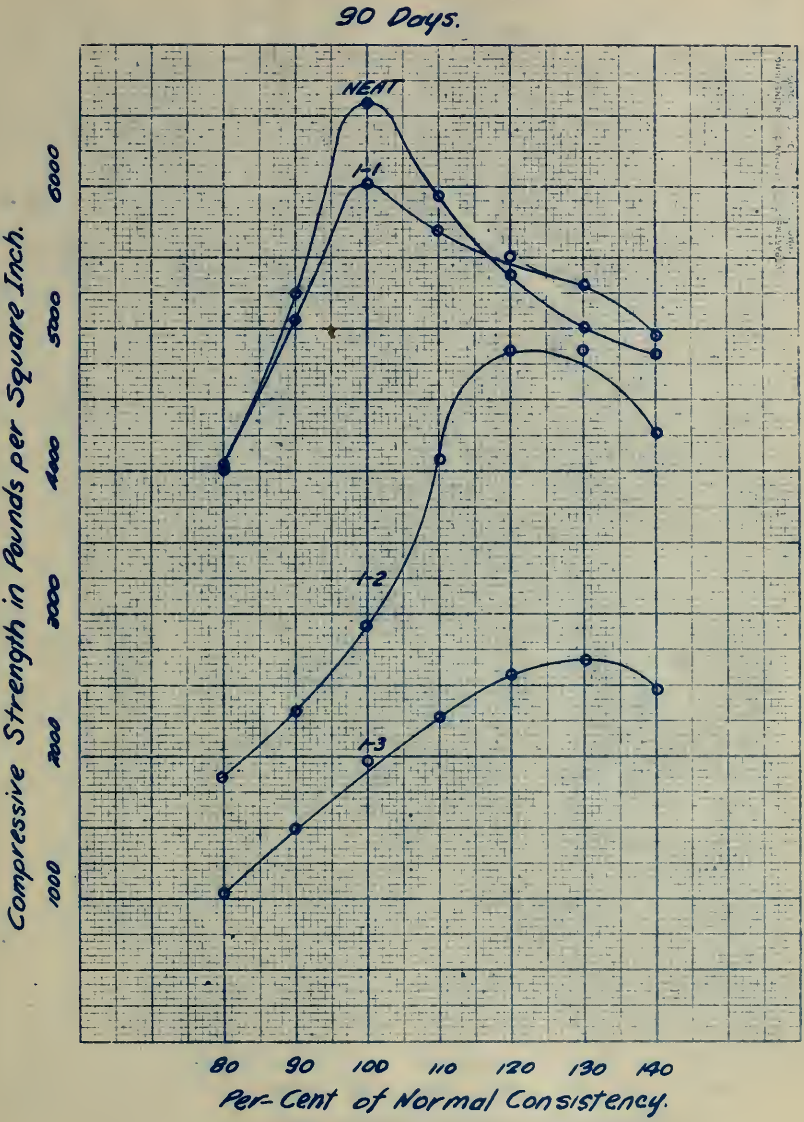


Curve 6.

28 Days.

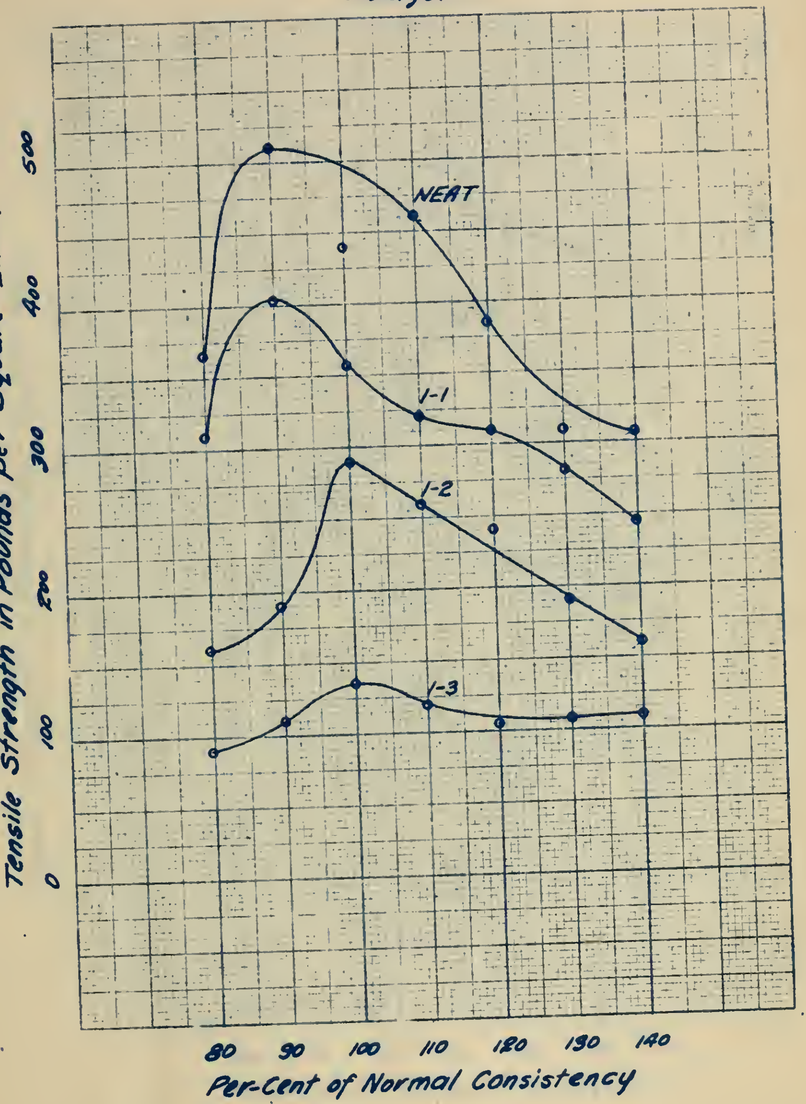


CURVE 7.


90 Days.

CURVE 8

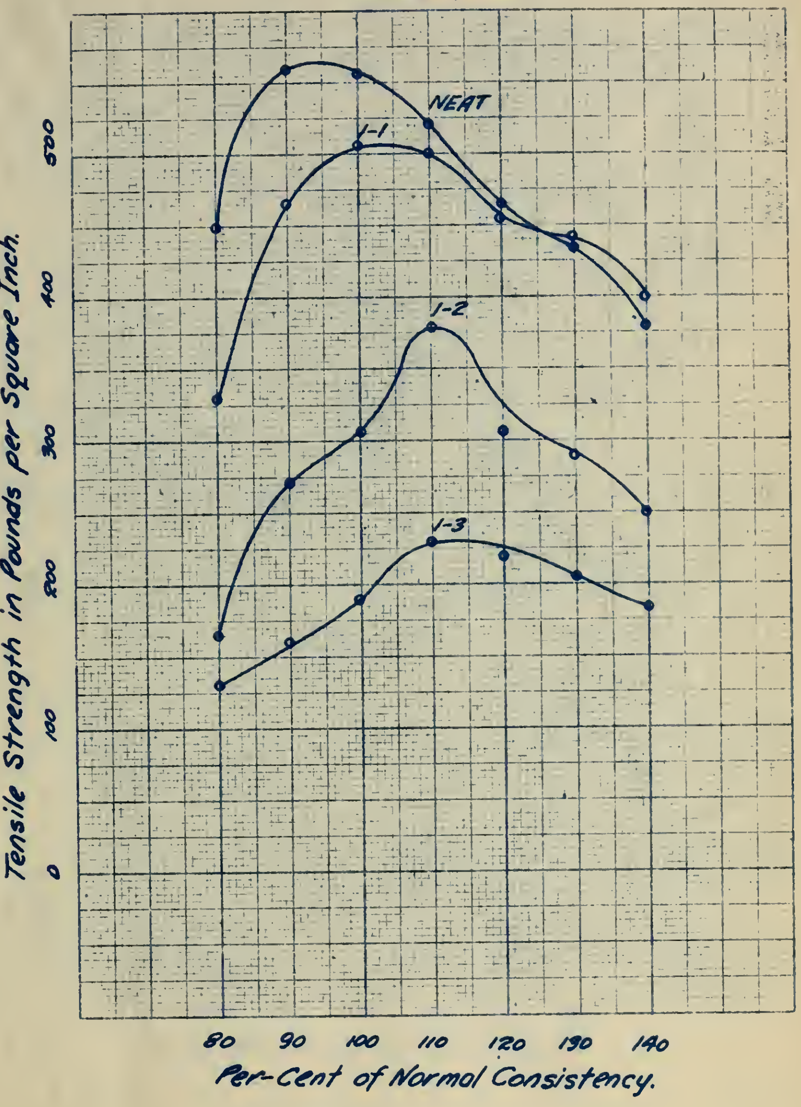
7 Days.



CURVE 9.

[illegible]

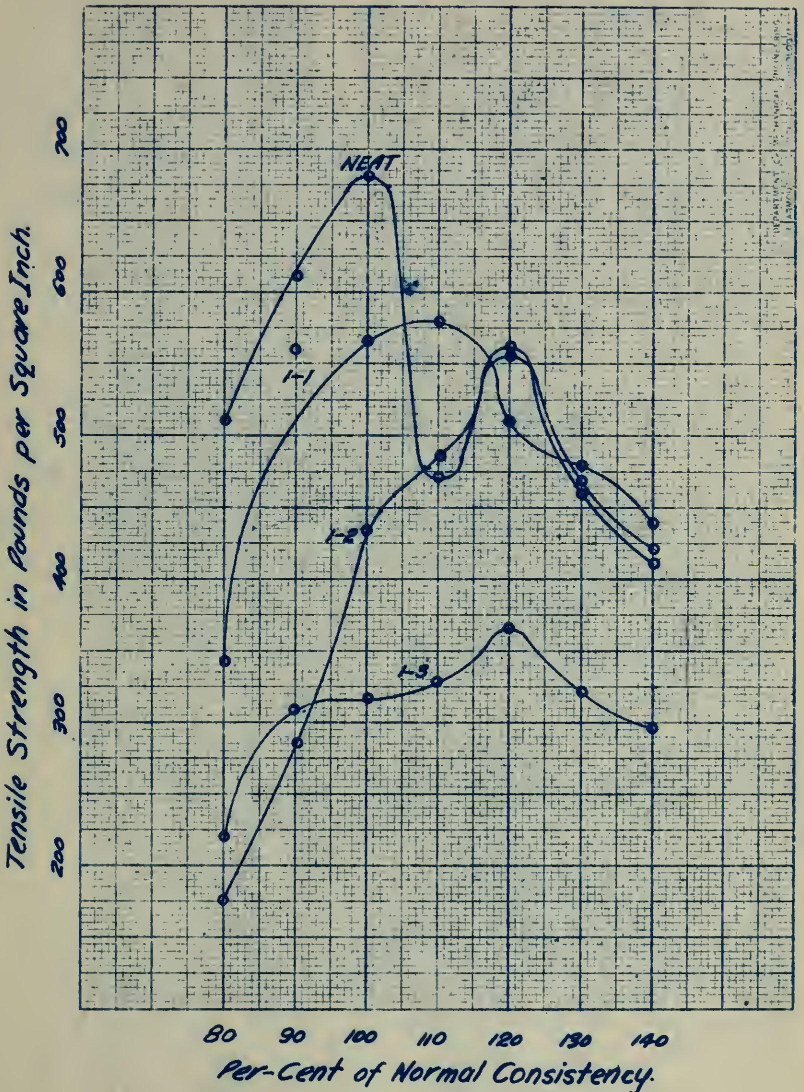
28 Days.



CURVE 10.

[illegible]

90 Days.



CURVE 11.

DATA FOR AVERAGE CURVE.

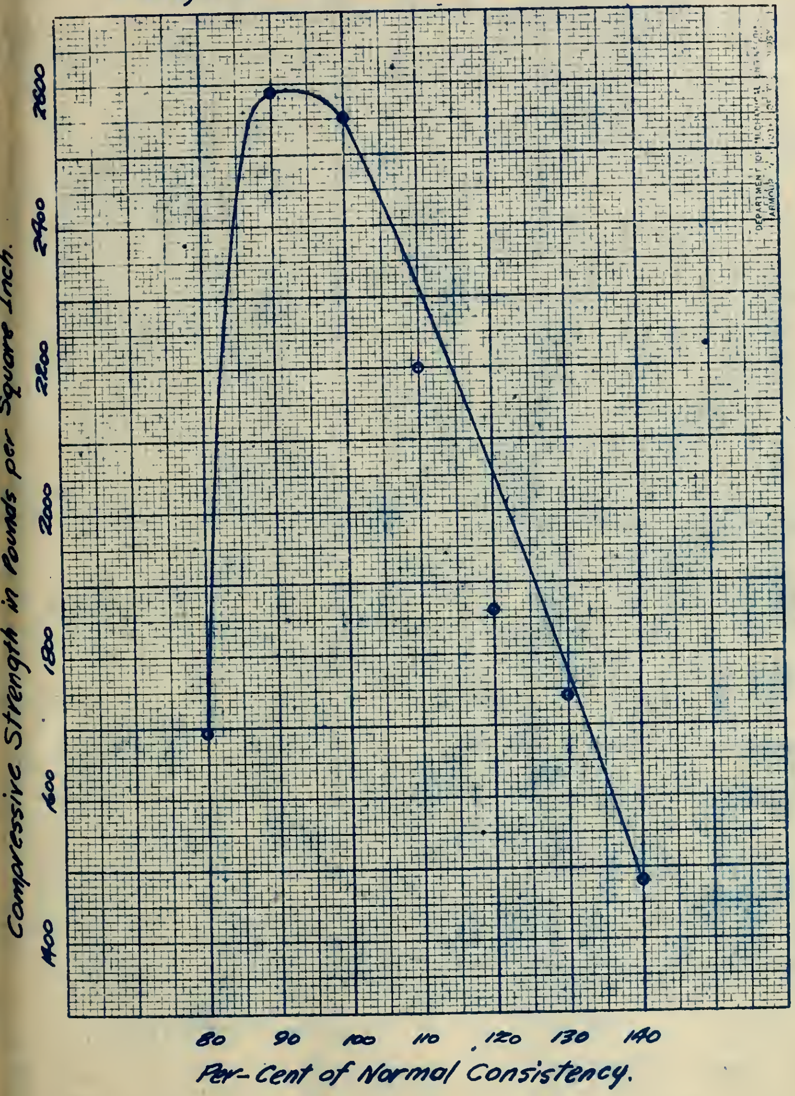
COMPRESSION

ABSCISSAE— PERCENT NORMAL CONSISTENCY. ORDINATES—COMPRESSIVE STRENGTHS.

AVERAGE OF MORTARS OF ALL PROPORTIONS. AGE 7 DAYS.

% OF NORMAL CONSISTENCY	80	90	100	110	120	130	140
NEAT CEMENT	2890	4560	4470	4060	3660	3420	3110
1-1 MORTAR	2110	3860	3450	2470	1920	1950	1460
1-2 MORTAR	1130	1230	1460	1570	1260	920	740
1-3 MORTAR	620	710	820	700	600	680	600
TOTAL	6750	10360	10200	8800	7440	6970	5910
AVERAGE	1690	2590	2550	2200	1860	1740	1480

Average Curve — All Mortars — 7 Days.



CURVE 12.

DATA FOR AVERAGE CURVE

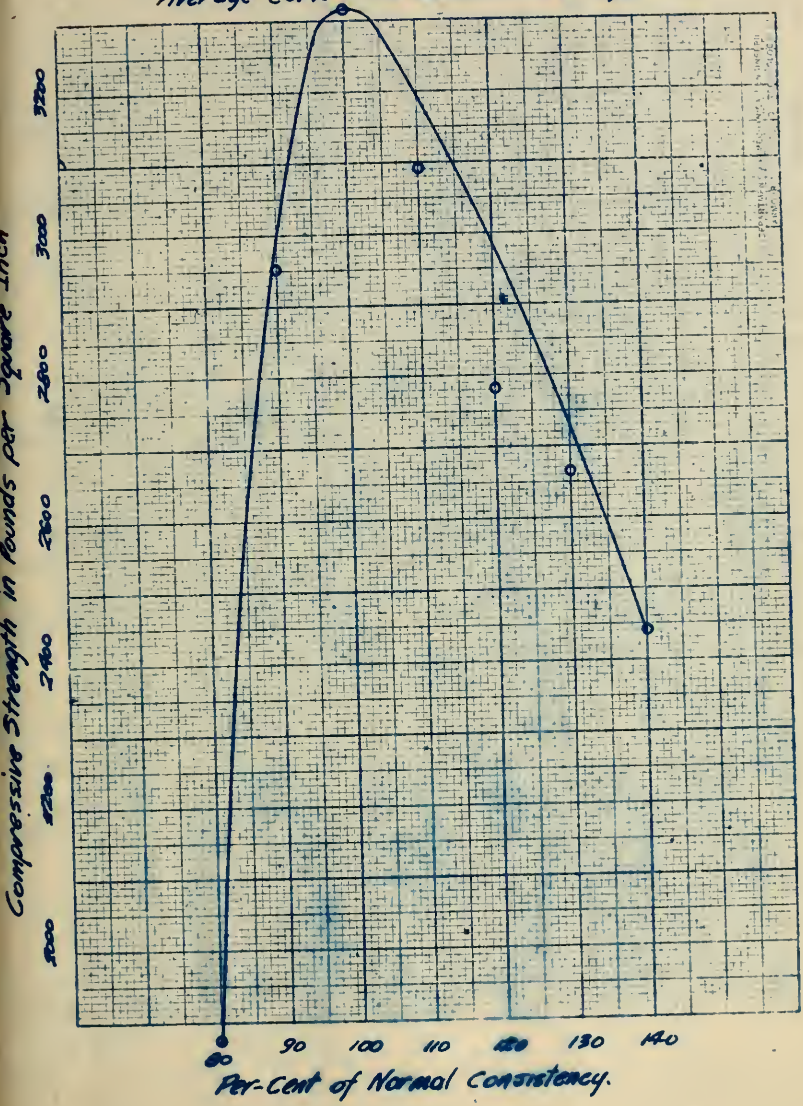
COMPRESSION

ABSCISSAE—PERCENT NORMAL CONSISTENCY. ORDINATES—COMPRESSIVE STRENGTHS.

AVERAGE OF MORTARS OF ALL PROPORTIONS. AGE 28 DAYS.

% OF NORMAL CONSISTENCY	80	90	100	110	120	130	140
NEAT CEMENT	3030	4760	4940	4380	3730	3570	3340
1-1 MORTAR	2300	3900	4420	3760	3630	3550	3260
1-2 MORTAR	1310	2040	2690	2760	2590	2470	2230
1-3 MORTAR	850	1100	1210	1450	1170	970	940
TOTAL	7490	11800	13260	12350	11120	10560	9770
AVERAGE	1870	2950	3320	3090	2780	2660	2440

Average Curve - All Mortars - 28 Days.



CURVE 13.

[illegible]

[illegible]

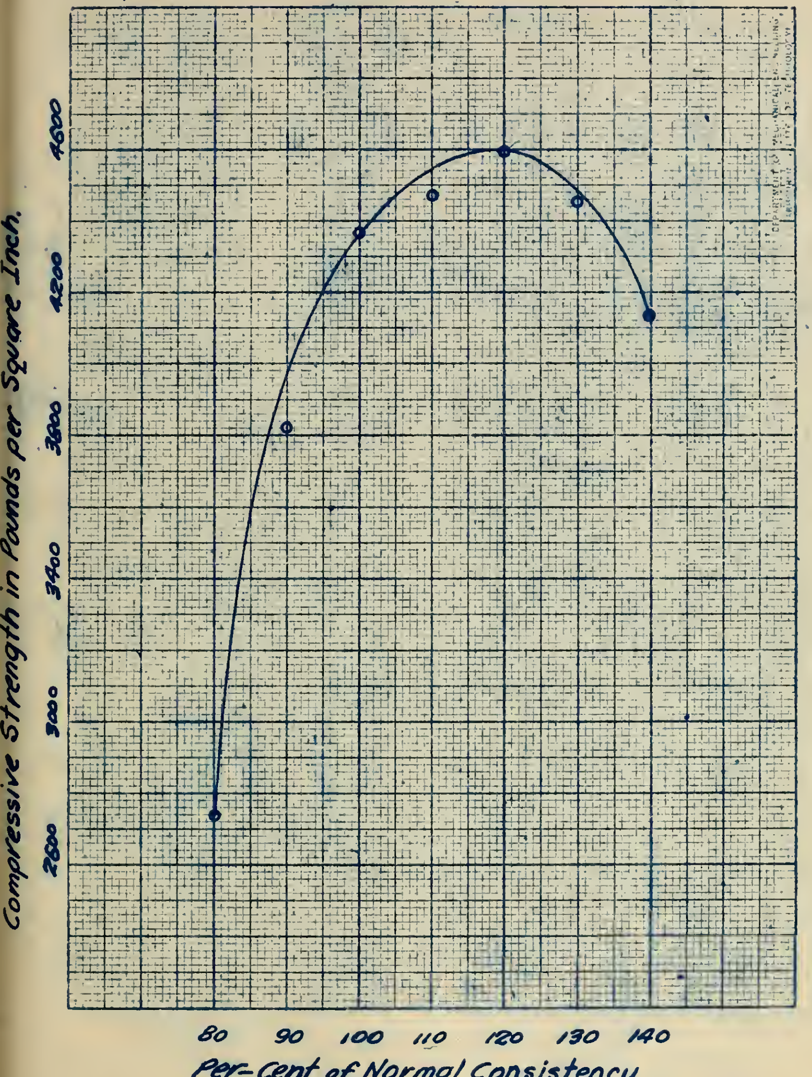
DATA FOR AVERAGE CURVE

COMPRESSION

ABSCISSAE— PERCENT NORMAL CONSISTENCY. ORDINATES—COMPRESSIVE STRENGTHS.

AVERAGE OF MORTARS OF ALL PROPORTIONS. AGE 90 DAYS.

% OF NORMAL CONSISTENCY.	80	90	100	110	120	130	140
NEAT CEMENT.	4010	5270	6570	5930	5420	4990	4810
1-1 MORTAR	4040	5060	6000	5640	5480	5320	4950
1-2 MORTAR	1840	2310	2920	4070	4860	4840	4260
1-3 MORTAR	1040	2610	1980	2250	2590	2650	2470
TOTAL	10930	15250	17470	17890	18350	17800	16490
AVERAGE	2730	3820	4370	4480	4590	4450	4120



Average Curve — All Mortars — 90 Days.

CURVE 14.

[illegible]

[illegible]

[illegible]

DATA FOR AVERAGE CURVE

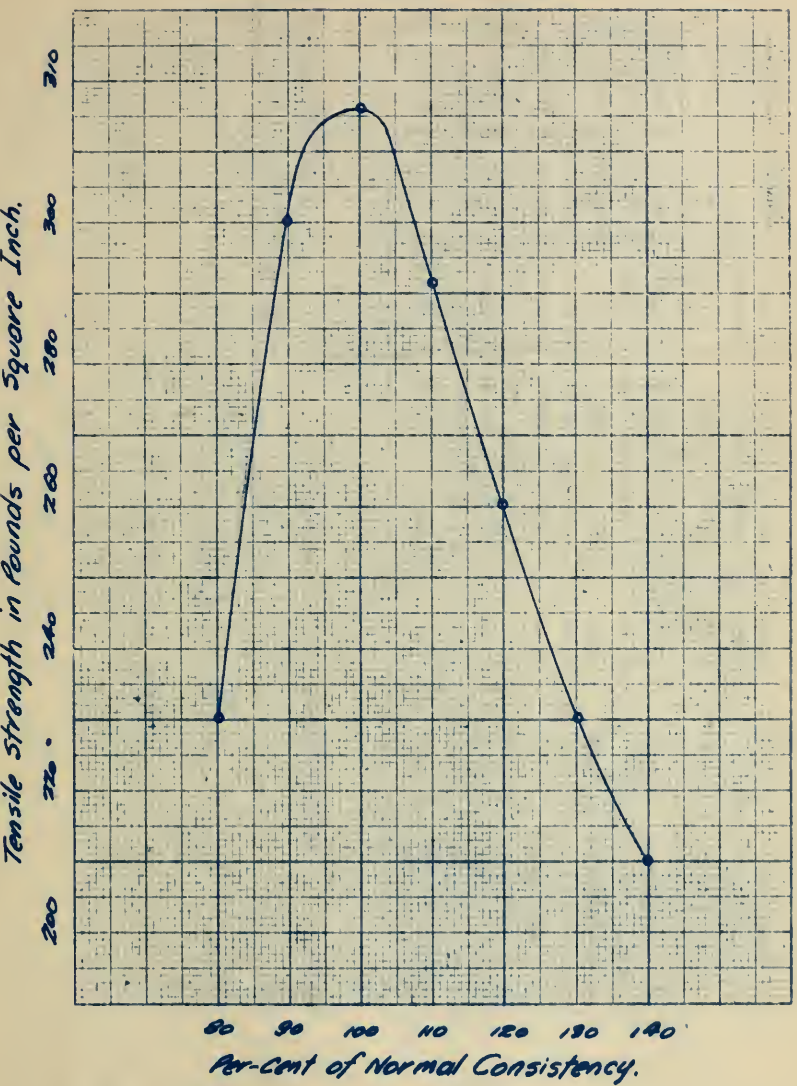
TENSION

ABSCISSAE — PERCENT NORMAL CONSISTENCY. ORDINATES — TENSILE STRENGTHS.

AVERAGE OF MORTARS OF ALL PROPORTIONS. AGE 7 DAYS.

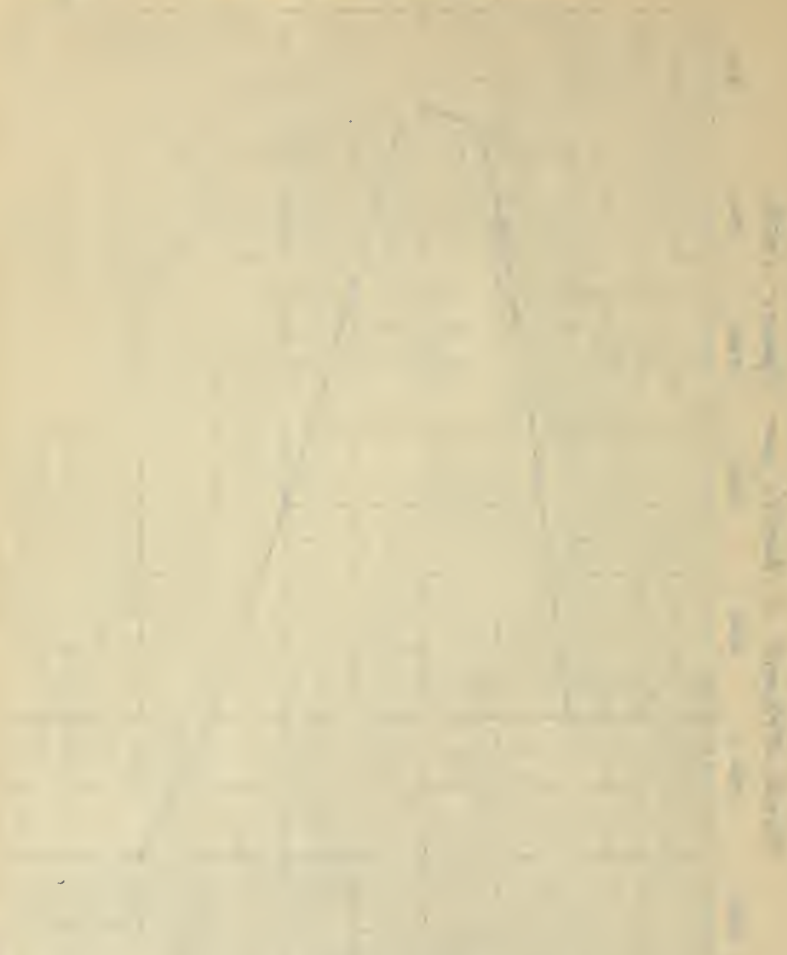
% OF NORMAL CONSISTENCY	80	90	100	110	120	130	140
NEAT CEMENT	365	510	445	465	385	310	305
1-1 MORTAR	310	405	355	320	310	280	245
1-2 MORTAR	155	175	290	260	240	190	160
1-3 MORTAR	90	110	135	120	105	140	110
TOTAL	920	1200	1225	1165	1040	920	820
AVERAGE	230	300	305	290	260	230	210

Average Curve- All Mortars- 7days.



CURVE 15.

[illegible]



[illegible]

DATA FOR AVERAGE CURVE

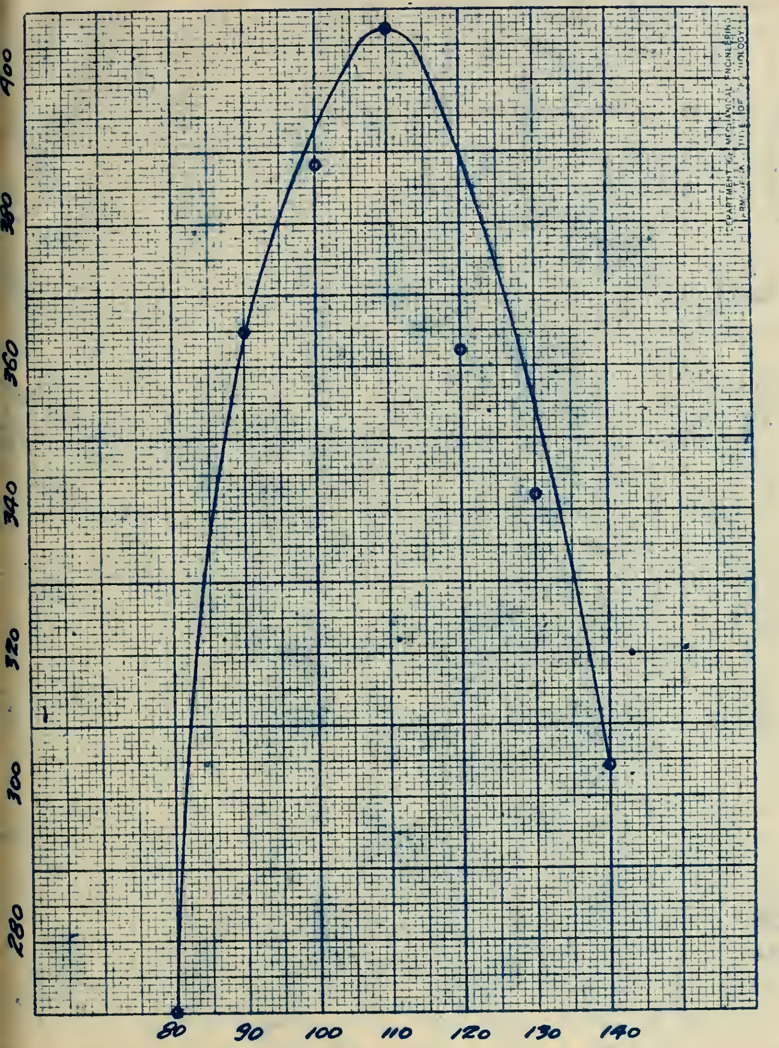
TENSION

ABSCISSAE — PERCENT NORMAL CONSISTENCY. ORDINATES — TENSILE STRENGTHS.

AVERAGE OF MORTARS OF ALL PROPORTIONS. AGE 28 DAYS.

% OF NORMAL CONSISTENCY	80	90	100	110	120	130	140
NEAT CEMENT	455	565	555	520	465	435	380
1-1 MORTAR	330	465	505	500	455	440	400
1-2 MORTAR	165	270	305	380	310	290	250
1-3 MORTAR	130	160	190	230	220	205	185
TOTAL	1080	1460	1555	1630	1450	1370	1215
AVERAGE	270	365	390	405	360	340	305

Average Curve- All Mortars - 28 Days.



CURVE 16.

DATA FOR AVERAGE CURVE.

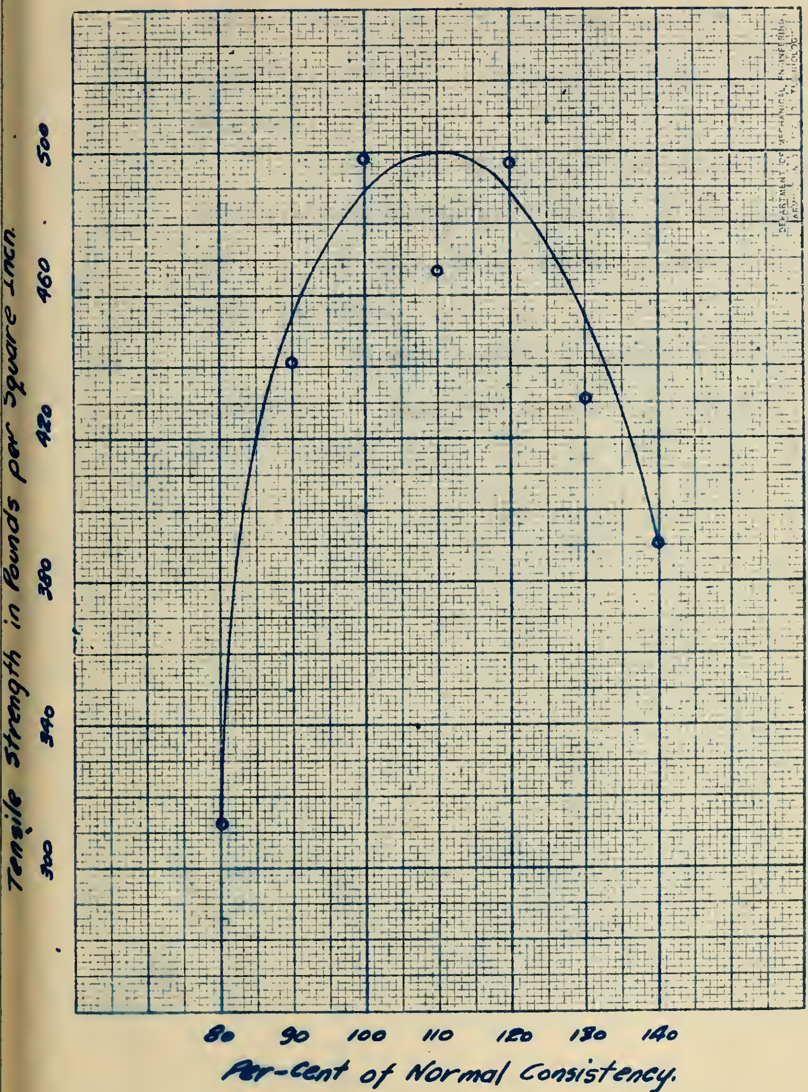
TENSION

ABSCISSAE— PERCENT NORMAL CONSISTENCY. ORDINATES— TENSILE STRENGTHS.

AVERAGE OF MORTARS OF ALL PROPORTIONS. AGE 90 DAYS.

% OF NORMAL CONSISTENCY.	80	90	100	110	120	130	140
NEAT CEMENT	510	610	680	470	560	460	410
1-1 MORTAR	345	560	565	580	510	480	440
1-2 MORTAR	175	285	435	485	555	465	420
1-3 MORTAR	220	310	315	335	365	320	295
TOTAL	1250	1765	1995	1870	1990	1725	1565
AVERAGE	310	440	500	465	495	430	390

Average Curve- All Mortars- 90 Days.



CURVE 17.

[illegible]

[illegible]

In the following GENERAL CURVES, the results shown are the combined results for all specimens tested, irrespective of age and proportions.

The general curves, therefore are obtained by averaging the results of 420 specimens for the compression curve and 420 for the tension curve.

In this manner is shown the average results to be expected from a series of different mortars.

DATA FOR GENERAL CURVE.

COMPRESSION

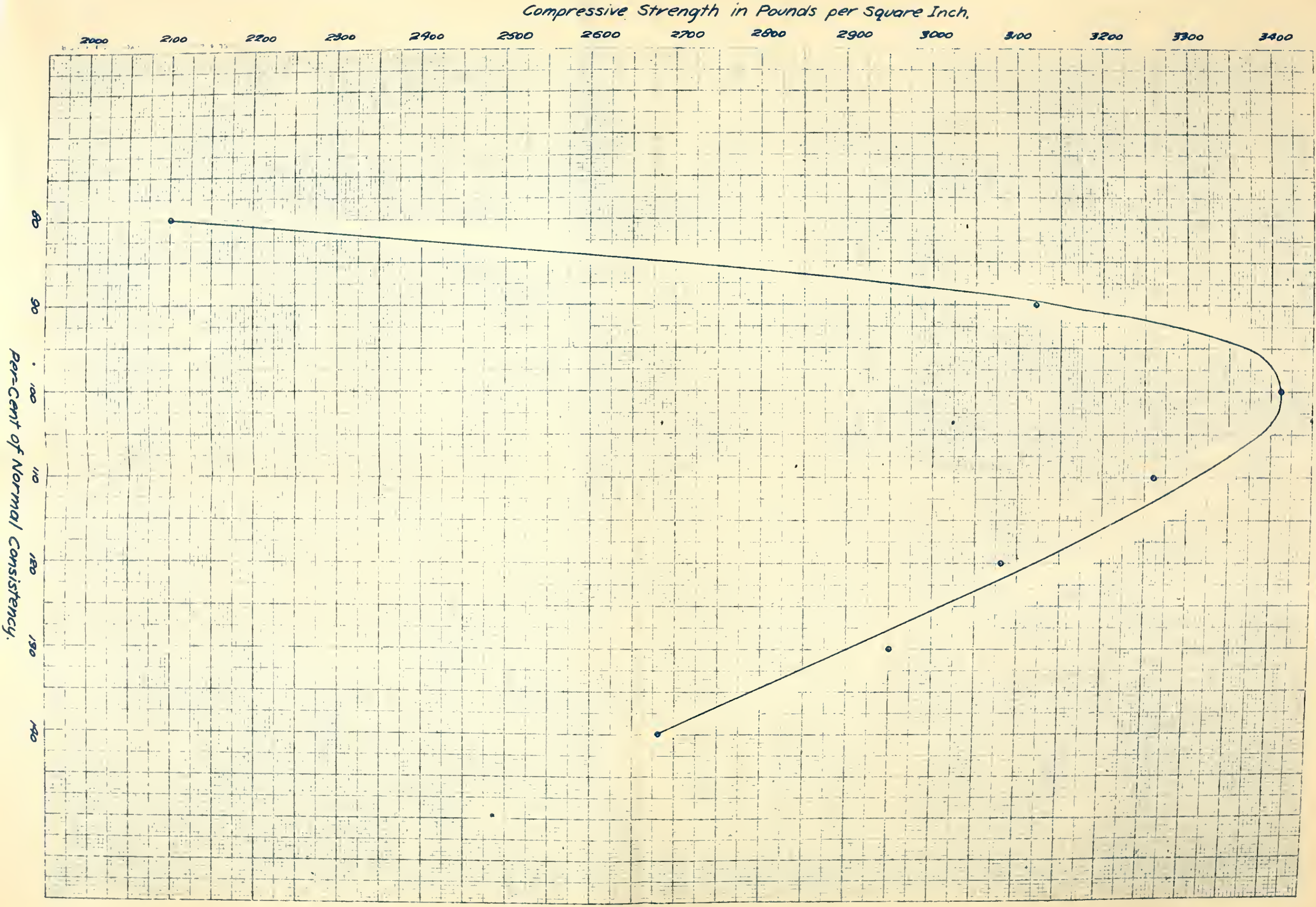
ABSCISSAE— PERCENT NORMAL CONSISTENCY. ORDINATES-COMPRESSIVE STRENGTHS.

AVERAGE OF MORTARS OF ALL PROPORTIONS AT ALL AGES.

% OF NORMAL CONSISTENCY.	80	90	100	110	120	130	140
AGES.							
7 DAYS.	1690	2590	2550	2200	1860	1740	1480
28 DAYS.	1870	2950	3320	3090	2780	2670	2440
90 DAYS	2730	3820	4370	4480	4590	4450	4120
TOTAL.	6290	9360	10240	9770	9230	8860	8040
AVERAGE.	2100	3120	3410	3260	3080	2950	2680

CURVE 18.

GENERAL CURVE - ALL MORTARS - ALL AGES.



DATA FOR GENERAL CURVE.

TENSION

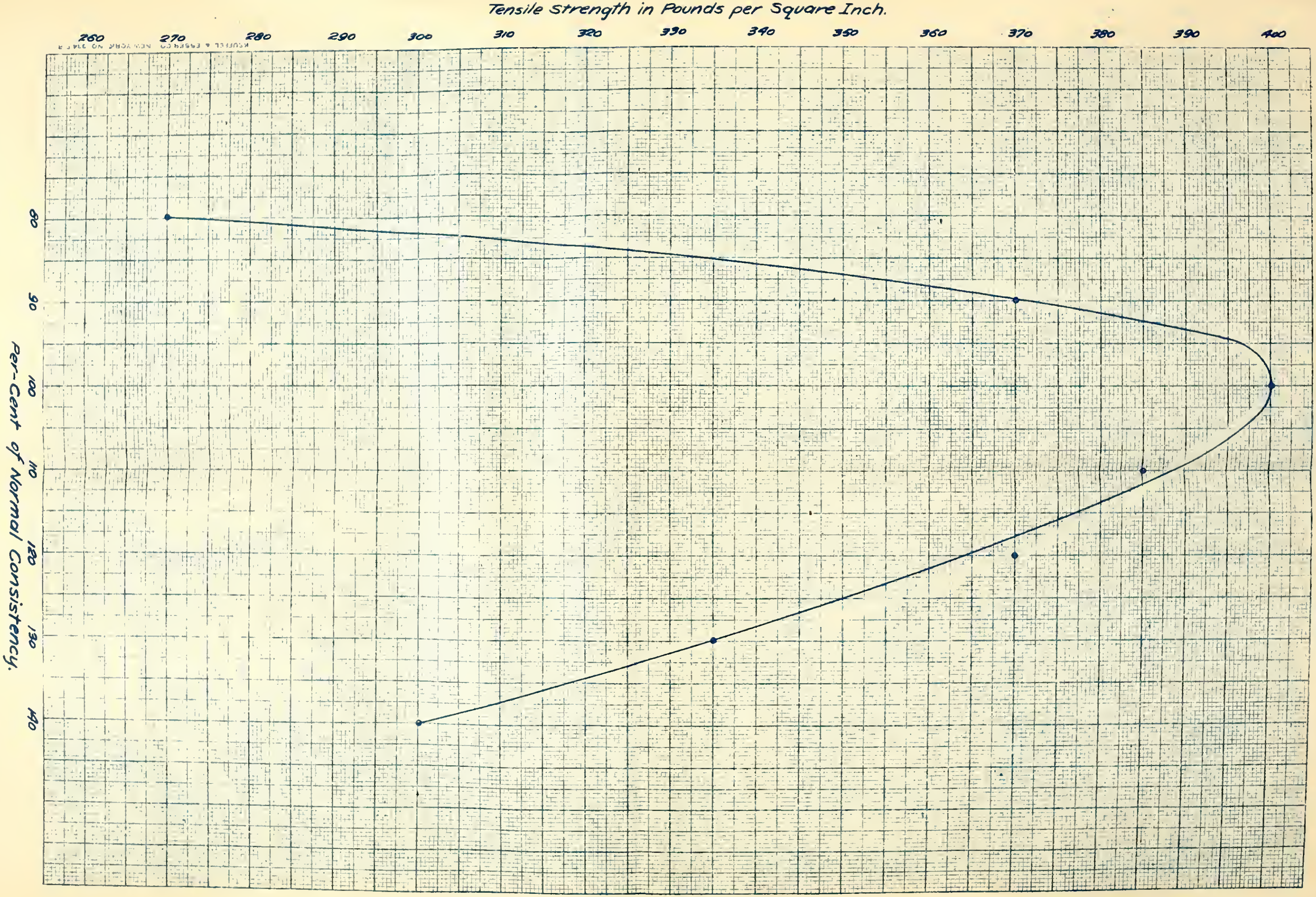
ABSCISSAE— PERCENT NORMAL CONSISTENCY. ORDINATES— TENSILE STRENGTHS.

AVERAGE OF MORTARS OF ALL PROPORTIONS AT ALL AGES

% OF NORMAL CONSISTENCY.	80	90	100	110	120	130	140
AGES.							
7 DAYS.	230	300	305	290	260	230	210
28 DAYS.	270	365	390	405	360	340	305
90 DAYS.	310	440	500	465	495	430	390
TOTAL.	810	1105	1195	1160	1115	1000	905
AVERAGE.	270	370	400	385	370	335	300

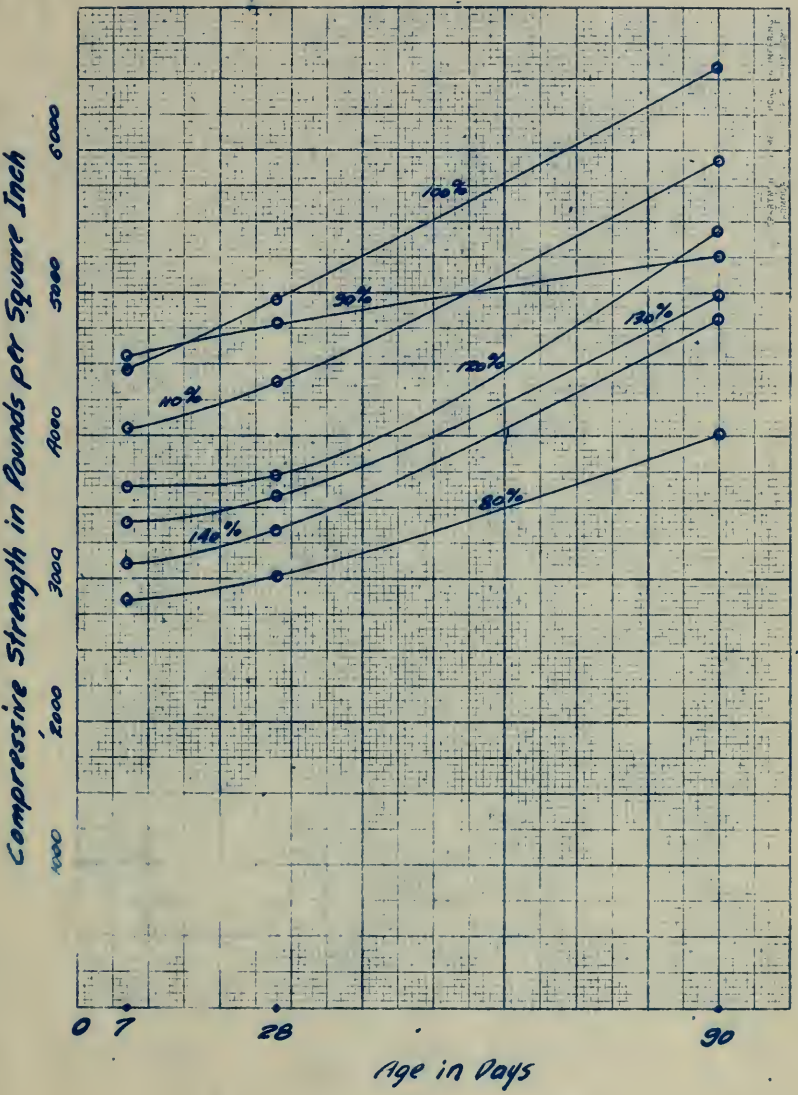
CURVE 19.

GENERAL CURVE - ALL MORTARS - ALL AGES.



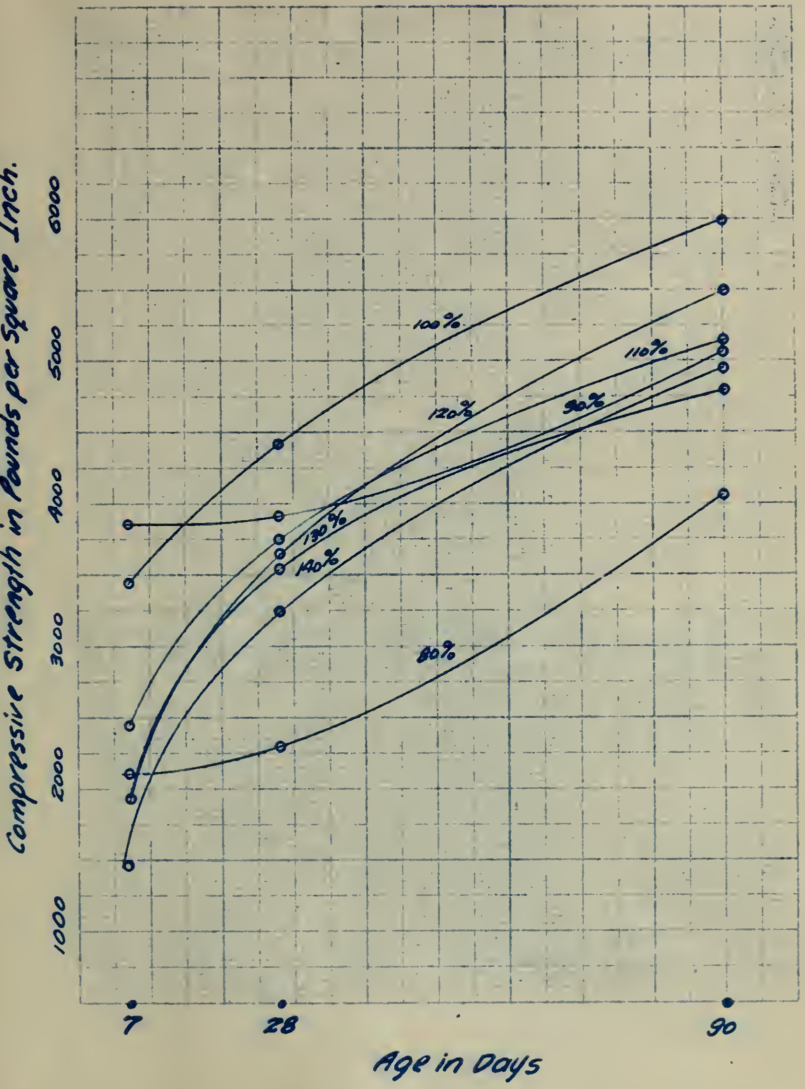
STRENGTH-AGE CURVES

Neat Cement.



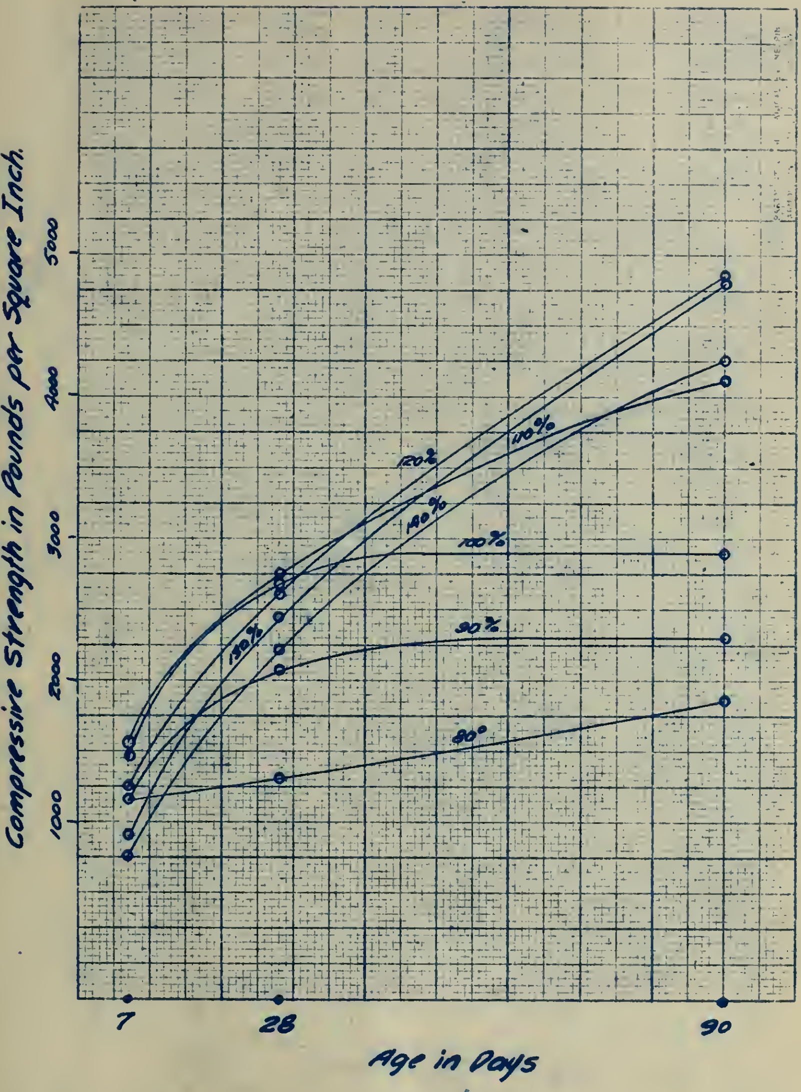
CURVE 20.

1-1 Mortar.



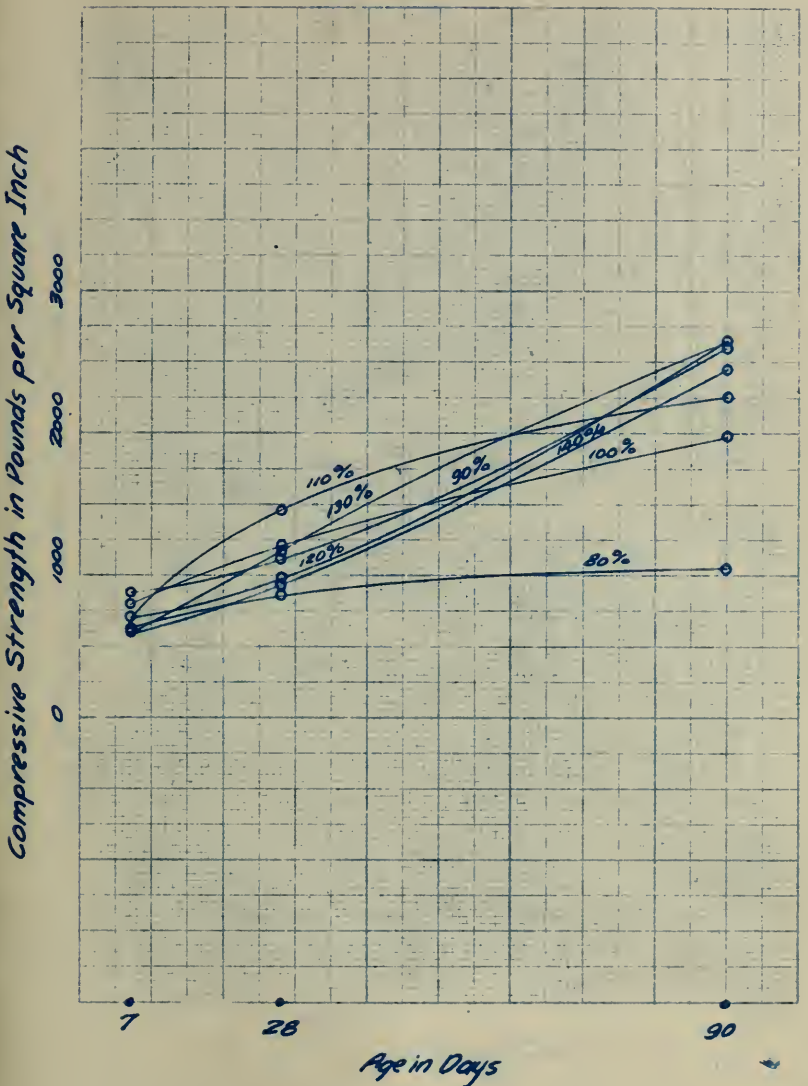
CURVE 21.

1-2 Mortar.



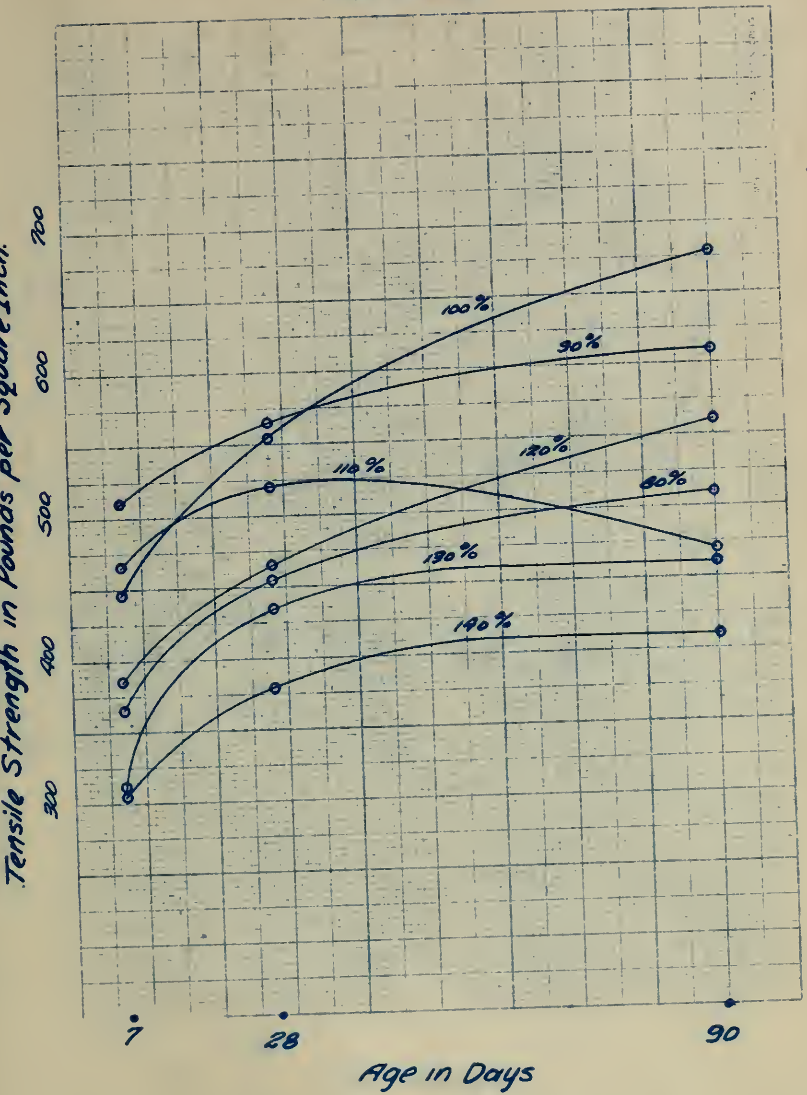
CURVE 22.

1-3 Mortar.



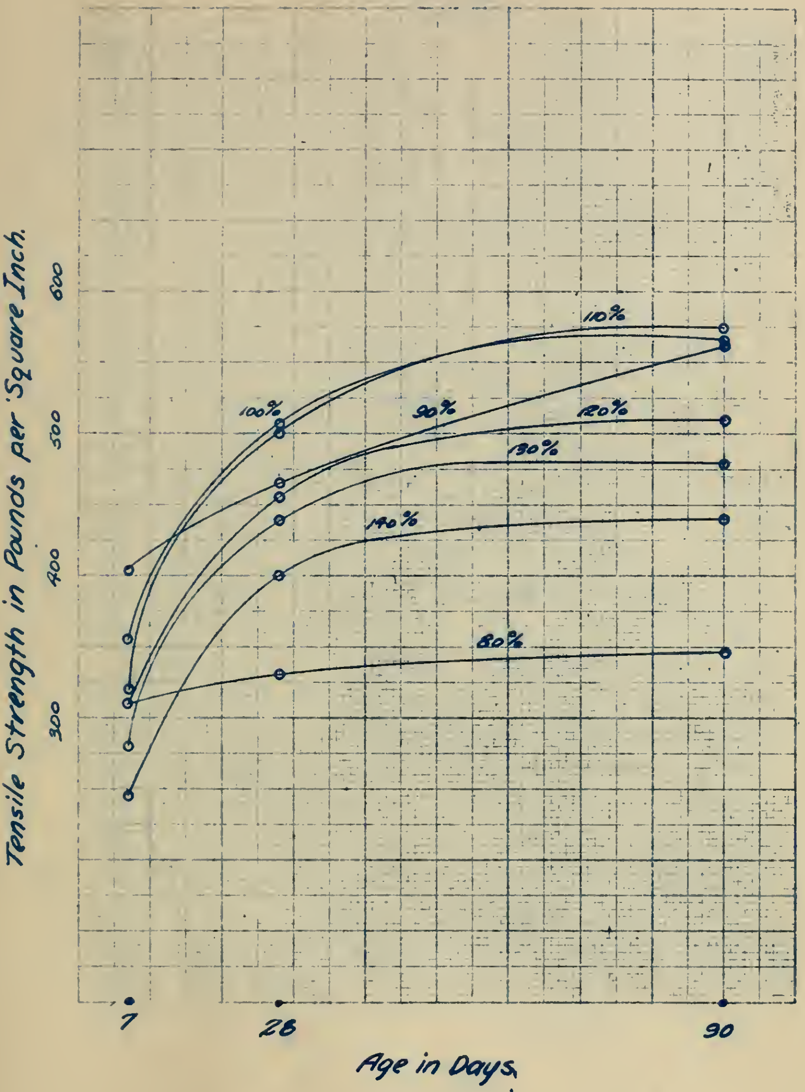
CURVE 23.

Neat Cement.



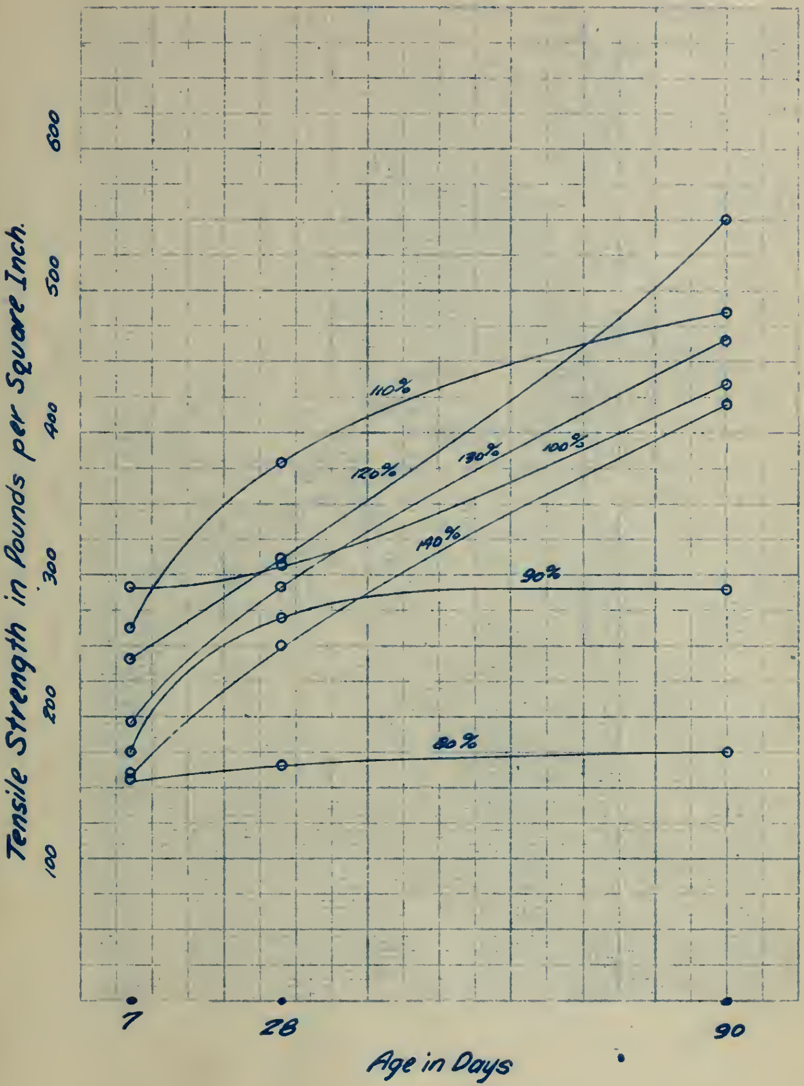
CURVE 24.

1-1 Mortar.



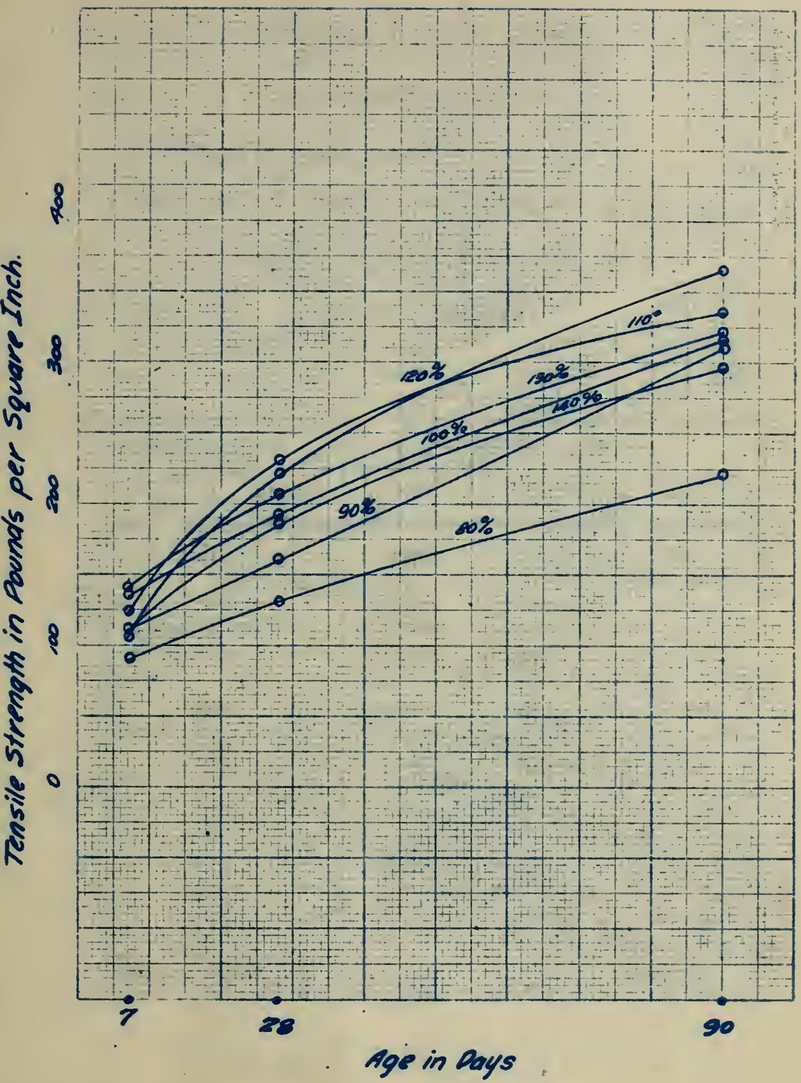
CURVE 25.

1-2 Mortar.



CURVE 26.

1-3 Mortar.



CURVE 27.

DATA FOR AVERAGE CURVE.

COMPRESSION.

ABSCISSAE — AGE IN DAYS.

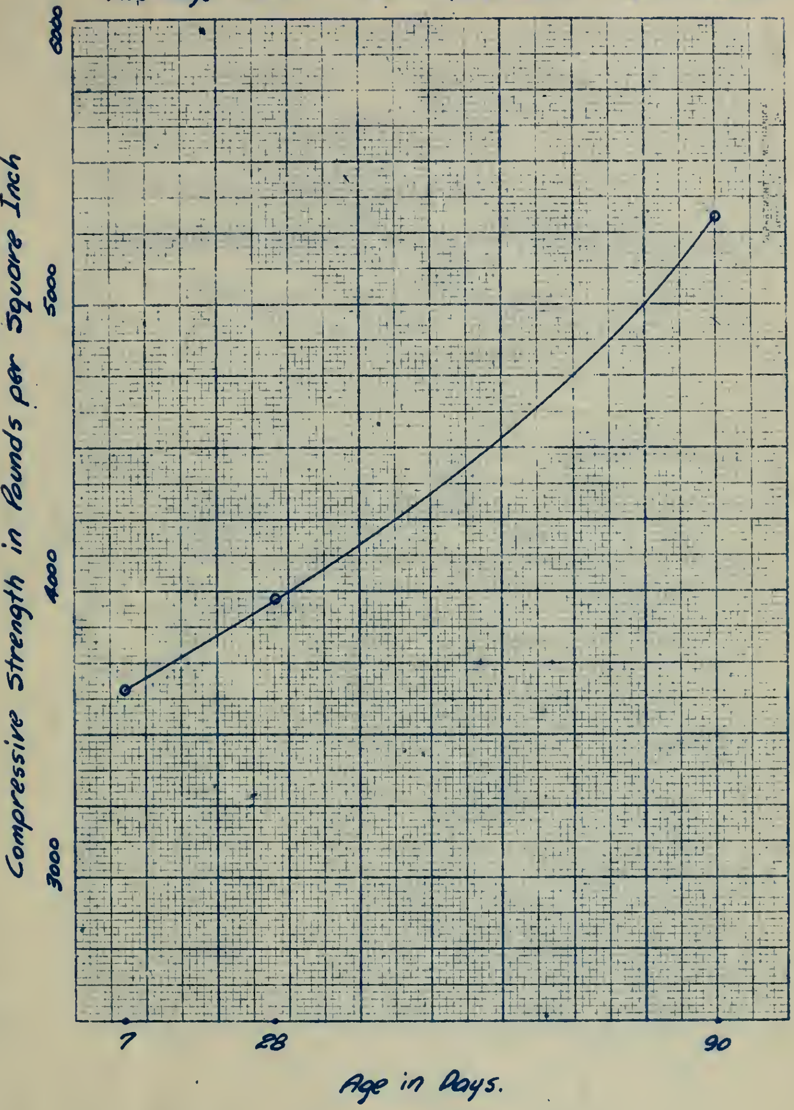
ORDINATES — COMPRE'N. STRENGTHS IN Llbs./sq.in.

AVERAGE OF ALL CONSISTENCIES.

NEAT CEMENT.

PERCENT OF NORMAL CONSISTENCY.	AGE IN DAYS.		
	7	28	90
80	2890	3030	4010
90	4560	4760	5270
100	4470	4940	6570
110	4060	4380	5930
120	3660	3730	5420
130	3420	3570	4990
140	3110	3340	4810
TOTAL.	26170	27750	37000
AVERAGE.	3650	3960	5290

Average Curve — All Consistencies — Neat Cement.



CURVE 28.

DATA FOR AVERAGE CURVE.

COMPRESSION.

ABSCISSAE – AGE IN DAYS.

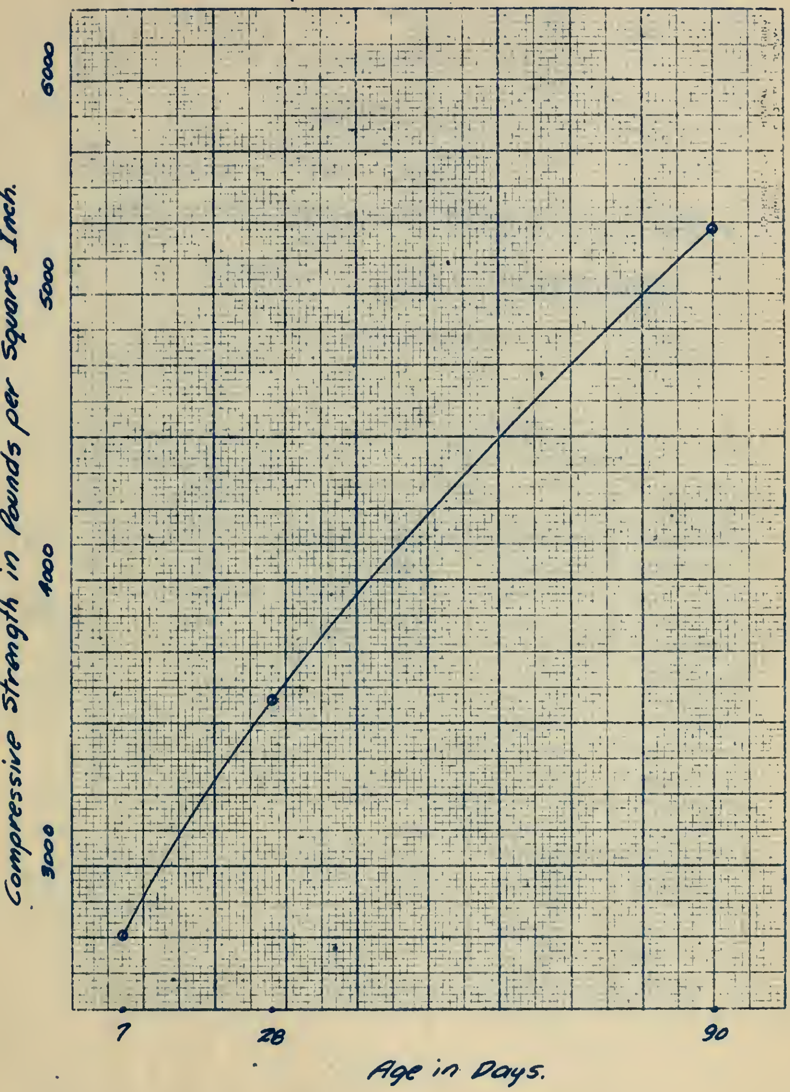
ORDINATES – COMPRE'N. STRENGTHS IN Llbs./sq.in.

AVERAGE OF ALL CONSISTENCIES.

1-1 MORTAR.

PERCENT OF NORMAL CONSISTENCY.	AGE IN DAYS.		
	7	28	90
80	2110	2300	4040
90	3860	3900	5060
100	3450	4420	6000
110	2470	3760	5640
120	1920	3630	5480
130	1950	3550	5320
140	1460	3260	4950
TOTAL.	17320	24820	36490
AVERAGE.	2770	3580	5210

Average Curve— All Consistencies— 1-1 Mortar.



CURVE 29.

DATA FOR AVERAGE CURVE.

COMPRESSION.

ABSCISSAE — AGE IN DAYS.

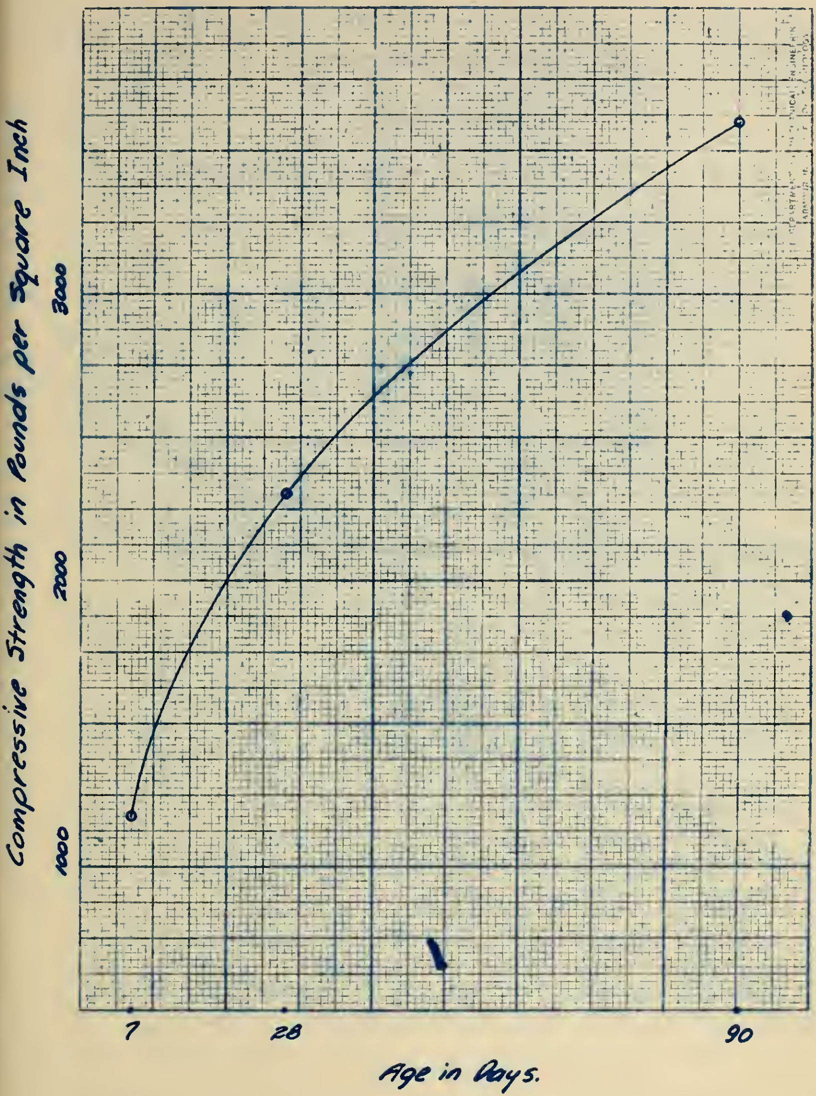
ORDINATES — COMPRE'N. STRENGTHS IN Lbs./sq. in.

AVERAGE OF ALL CONSISTENCIES.

1-2 MORTAR.

PERCENT OF NORMAL CONSISTENCY.	AGE IN DAYS.		
	7	28	90
80	1130	1310	1840
90	1230	2090	2310
100	1460	2690	2920
110	1570	2760	4080
120	1260	2540	4860
130	920	2470	4840
140	730	2230	4260
TOTAL.	8300	16090	25110
AVERAGE.	1190	2300	3590

Average Curve- All Consistencies- 1-2 Mortar



CURVE 30

DATA FOR AVERAGE CURVE.

COMPRESSION.

ABSCISSAE - AGE IN DAYS.

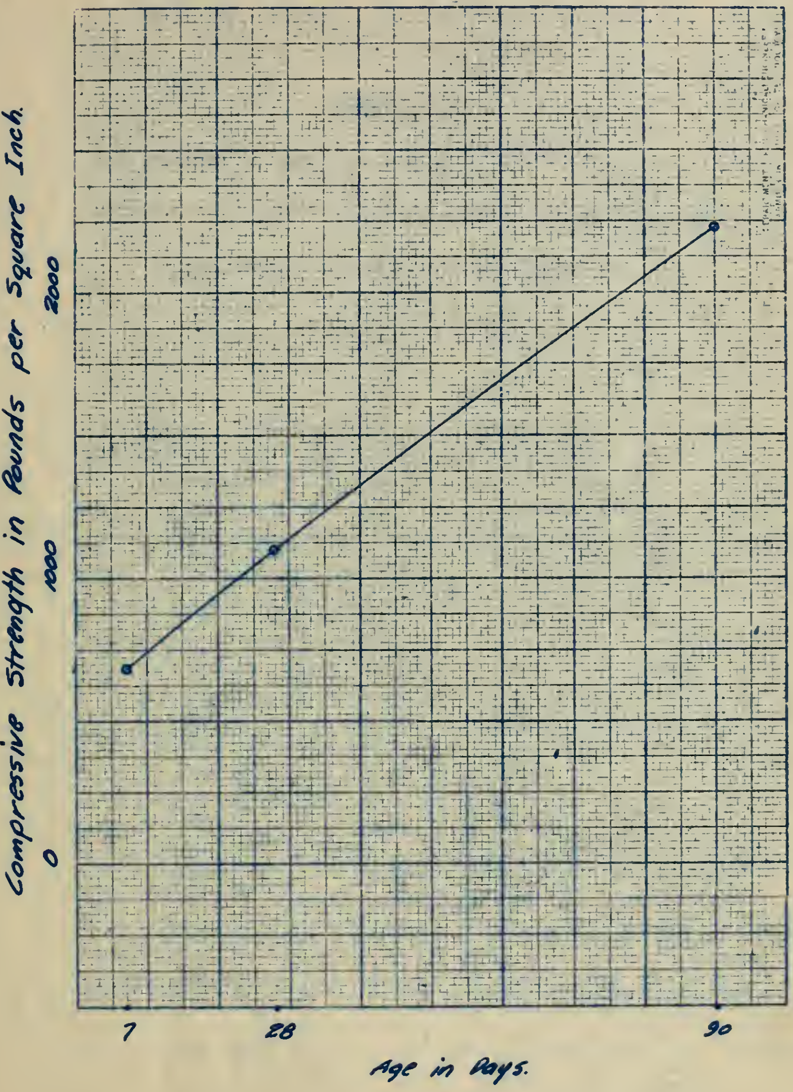
ORDINATES - COMPRE'N. STRENGTHS IN Lbs./sq. in.

AVERAGE OF ALL CONSISTENCIES.

1-3 MORTAR.

PERCENT OF NORMAL CONSISTENCY.	AGE IN DAYS.		
	7	28	90
80	620	850	1040
90	710	1100	2610
100	820	1210	1980
110	690	1450	2250
120	600	1170	2590
130	680	970	2650
140	600	940	2470
TOTAL.	4720	7690	15590
AVERAGE.	670	1100	2230

Average Curve— All Consistencies— 1-3 Mortar.



CURVE 31.

DATA FOR AVERAGE CURVE.

TENSION.

ABSCISSAE — AGE IN DAYS.

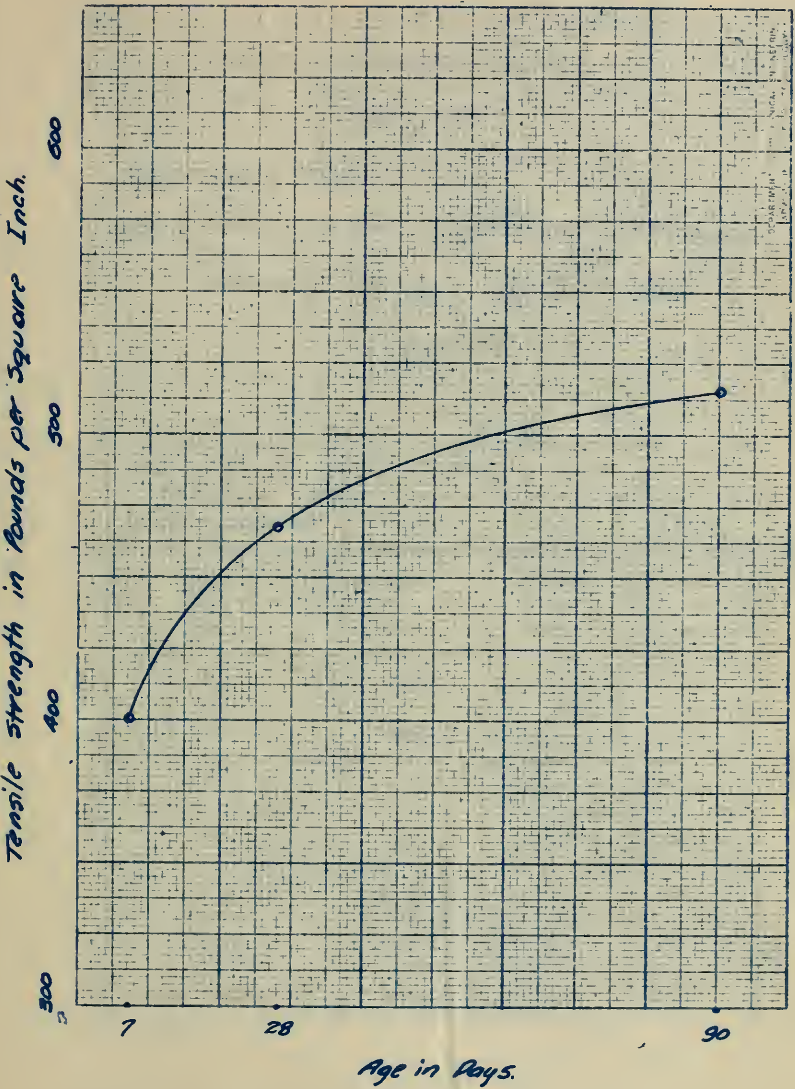
ORDINATES — TENSILE STRENGTHS IN Lbs./sq. in.

AVERAGE OF ALL CONSISTENCIES.

NEAT CEMENT.

PERCENT OF NORMAL CONSISTENCY.	AGE IN DAYS.		
	7	28	90
80	365	455	510
90	510	565	610
100	445	555	680
110	465	520	470
120	385	465	560
130	310	435	460
140	305	380	410
TOTAL	2785	3375	3700
AVERAGE.	400	480	615

Average Curve— All Consistencies — Neat Cement.



CURVE 32.

DATA FOR AVERAGE CURVE.

TENSION

ABSCISSAE - AGE IN DAYS.

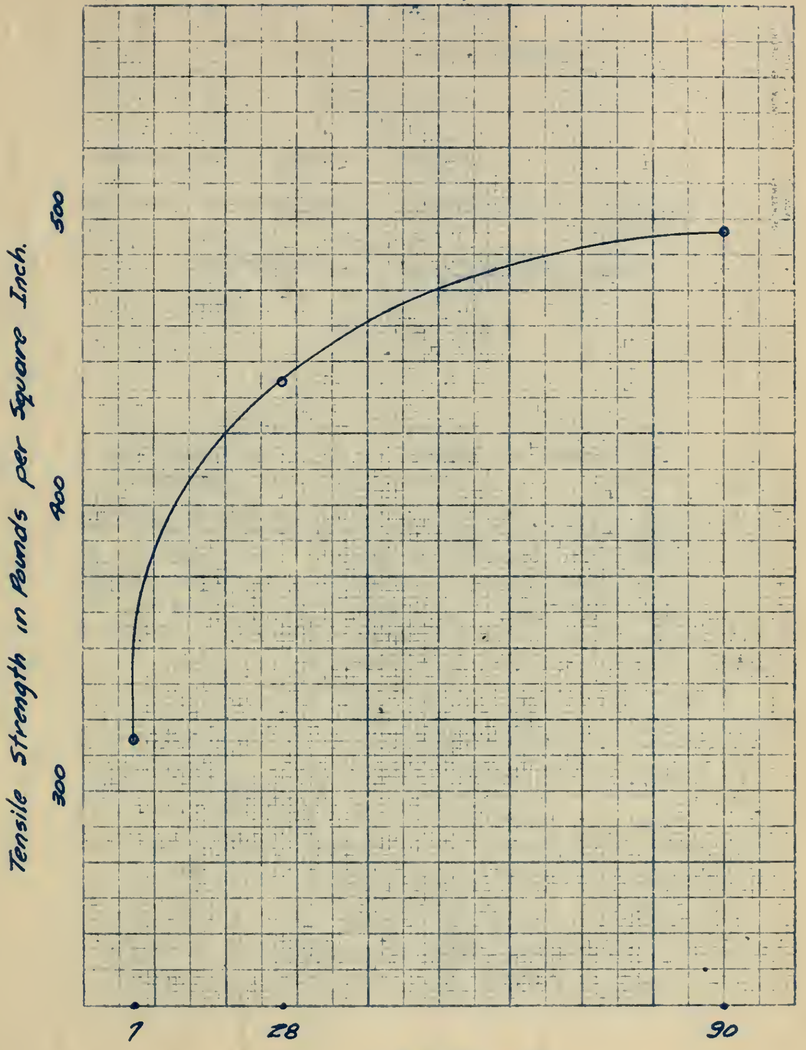
ORDINATES - TENSILE STRENGTHS IN Llbs./sq. in.

AVERAGE OF ALL CONSISTENCIES.

1-1 MORTAR.

PERCENT OF NORMAL CONSISTENCY.	AGE IN DAYS.		
	7	28	90
80	310	330	340
90	405	465	560
100	355	505	565
110	320	500	580
120	310	455	510
130	280	440	480
140	245	400	440
TOTAL	2225	3095	3475
AVERAGE.	320	440	495

Average Curve— All Consistencies — 1-1 Mortar.



Age in Days.

CURVE 33.

[illegible]

DATA FOR AVERAGE CURVE.

TENSION

ABSCISSAE – AGE IN DAYS.

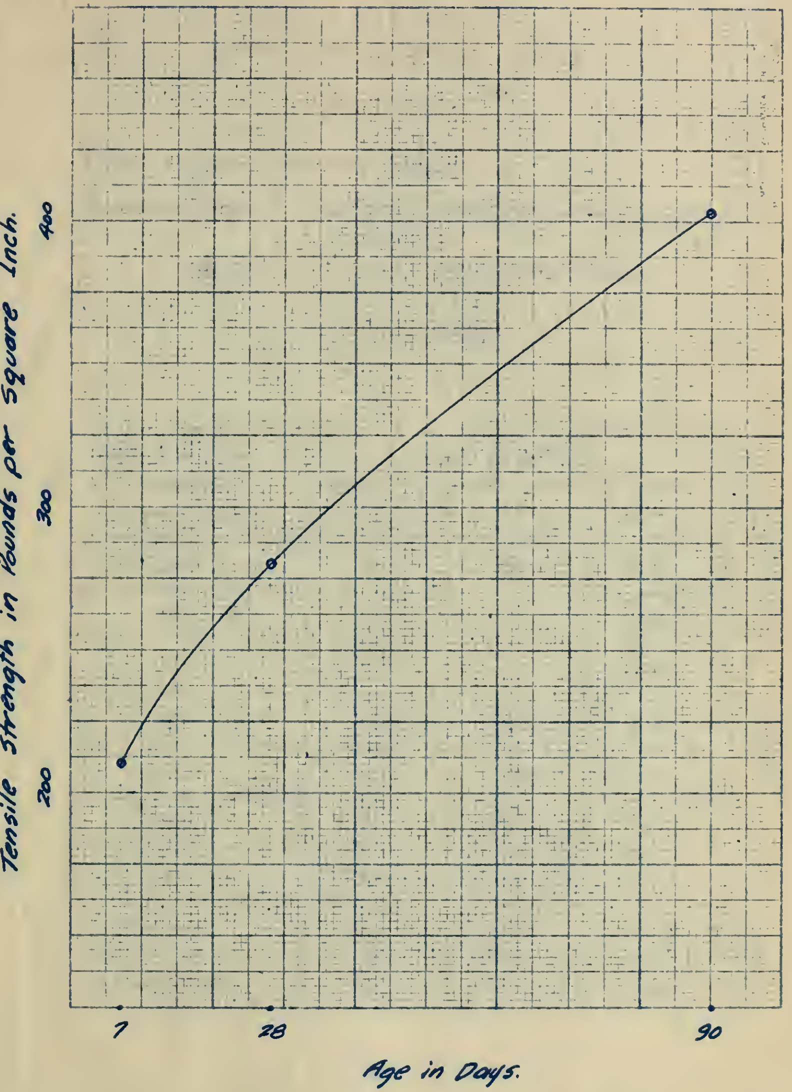
ORDINATES – TENSILE STRENGTHS IN Lbs./sq. in.

AVERAGE OF ALL CONSISTENCIES.

1-2 MORTAR

PERCENT OF NORMAL CONSISTENCY.	AGE IN DAYS.		
	7	28	90
80	155	165	175
90	175	270	285
100	290	305	435
110	260	380	485
120	240	310	555
130	190	290	465
140	160	250	420
TOTAL	1470	1970	2820
AVERAGE.	210	280	405

Average Curve— All Consistencies — 1-2 Mortar.



CURVE 34.

DATA FOR AVERAGE CURVE.

TENSION.

ABSCISSAE - AGE IN DAYS.

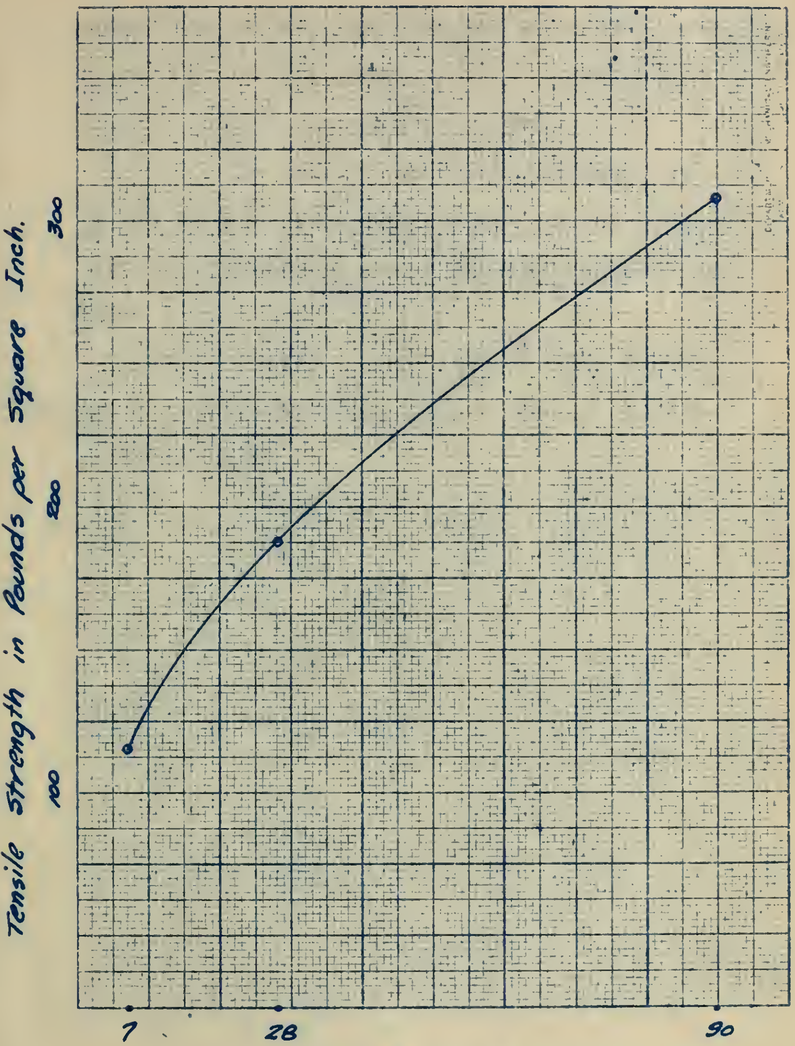
ORDINATES - TENSILE STRENGTHS IN Lbs./sq.in.

AVERAGE OF ALL CONSISTENCIES.

1:3 MORTAR.

PERCENT OF NORMAL CONSISTENCY.	AGE IN DAYS.		
	7	28	90
80	90	130	220
90	110	160	310
100	135	190	315
110	120	230	335
120	105	220	365
130	140	205	320
140	110	185	295
TOTAL	810	1320	2160
AVERAGE	115	190	310

Average Curve — All Consistencies — 1-3 Mortar.



CURVE 35.

In the following GENERAL CURVES, the results shown are the combined results for all specimens tested, irrespective of percentage of normal consistency or proportions.

The general curves, therefore are obtained by averaging the results of 420 specimens for the compression curve and 420 for the tension curve.

In this manner is shown the average results to be expected from a series of different mortars.

DATA FOR GENERAL CURVE.

COMPRESSION.

ABSCISSAE - AGE IN DAYS.

ORDINATES - COMPRE'N. STRENGTHS IN Lbs./sq. in.

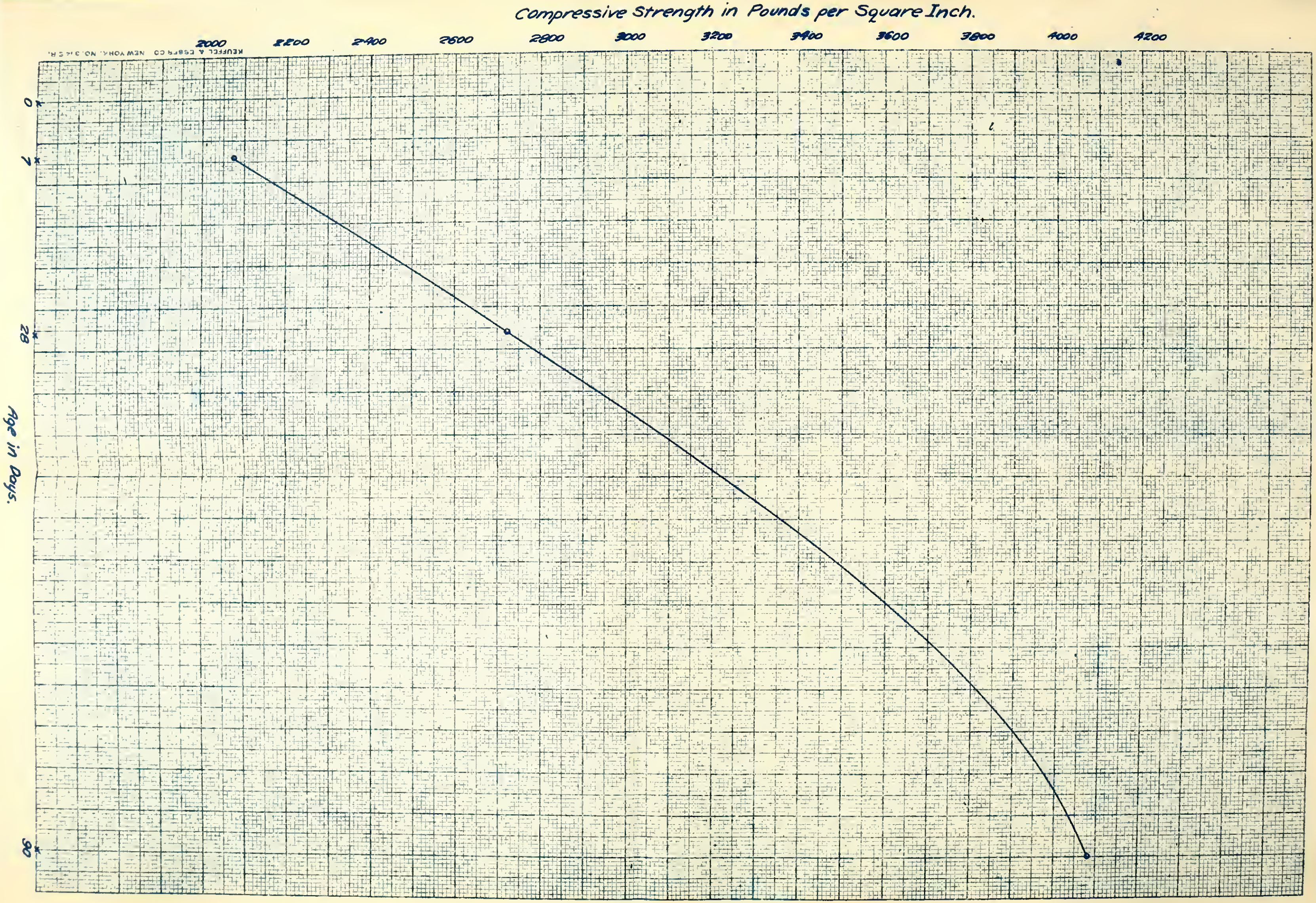
AVERAGE OF ALL CONSISTENCIES.

AVERAGE OF ALL PROPORTIONS.

PROPORTIONS.	AGE IN DAYS.		
	7	28	90
NEAT CEMENT.	3650	3960	5290
1-1 MORTAR.	2770	3580	5210
1-2 MORTAR.	1190	2300	3590
1-3 MORTAR.	670	1100	2230
TOTAL.	8280	10940	16320
AVERAGE.	2070	2720	4080

CURVE 36.

GENERAL CURVE - ALL MORTARS - ALL CONSISTENCIES.



DATA FOR GENERAL CURVE.

TENSION

ABSCISSAE – AGE IN DAYS.

ORDINATES – TENSILE STRENGTHS IN Libs./sq. in.

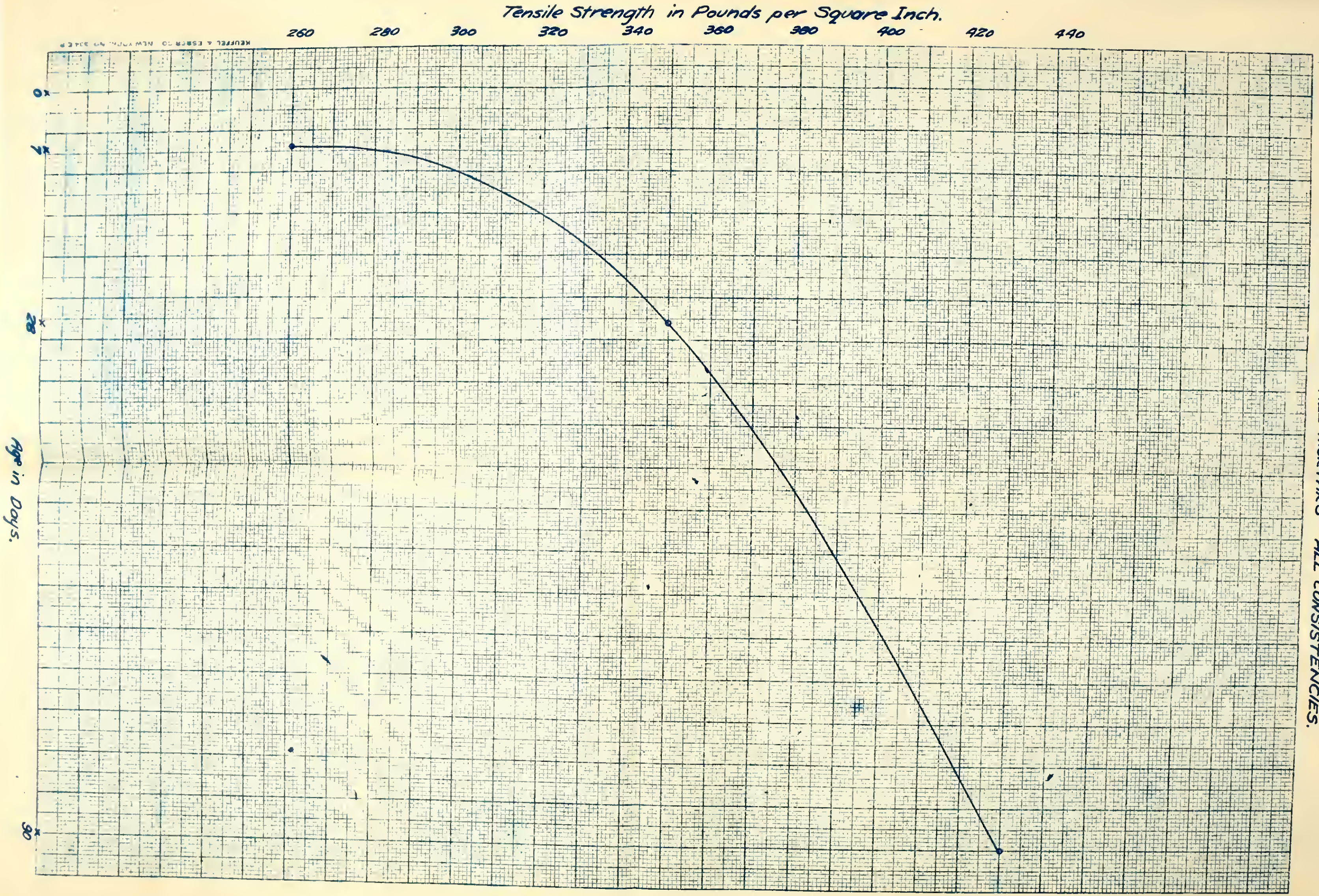
AVERAGE OF ALL CONSISTENCIES.

AVERAGE OF ALL PROPORTIONS.

PROPORTIONS	AGE IN DAYS		
	7	28	90
NEAT CEMENT.	400	480	515
1-1 MORTAR.	315	440	495
1-2 MORTAR.	210	280	405
1-3 MORTAR.	115	190	310
TOTAL.	1040	1390	1725
AVERAGE.	260	350	430

CURVE 37.

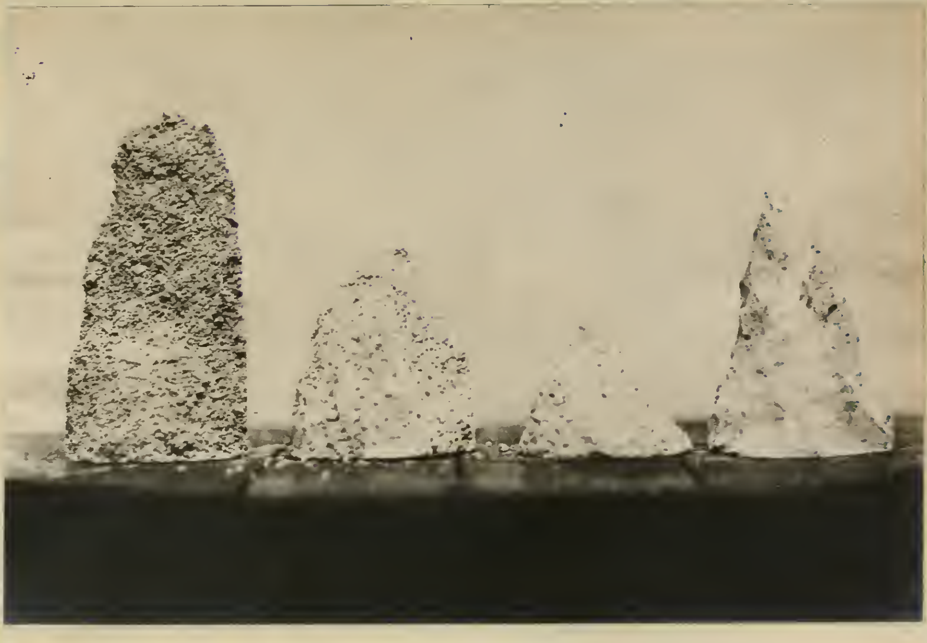
GENERAL CURVE - ALL MORTARS - ALL CONSISTENCIES.



Typical Failures.

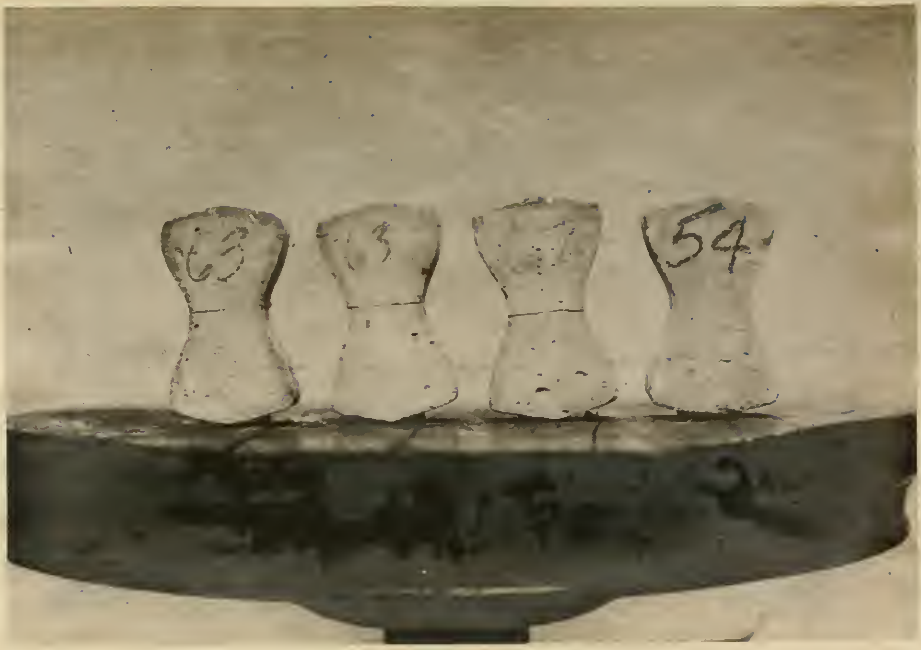
On page 179, ,Fig. 20 is shown some typical specimens after failue due to compressive stresses induced by loading. Reading from left to right the specimens consist of 1 - 3 Mortar, 1 - 2 Mortar, 1 - 3 Mortar, and Neat Cement. From the illustration it will be seen that the mixes containing the smaller amounts of sand resulted in specimens which showed the cleanest breaks. The most perfect cone was provided by the specimens of neat cement.

Fig. 21, page 180, shows some typical tension failures. Most of the specimens of all mixes broke evenly and near the center although the leaner mixes at the shorter ages showed a tendency to break near the shoulders.



TYPICAL FAILURES — COMPRESSION SPECIMENS.

Fig. 20.



TYPICAL FAILURES. TENSION SPECIMENS.

Fig. 21.

CHAPTER VI

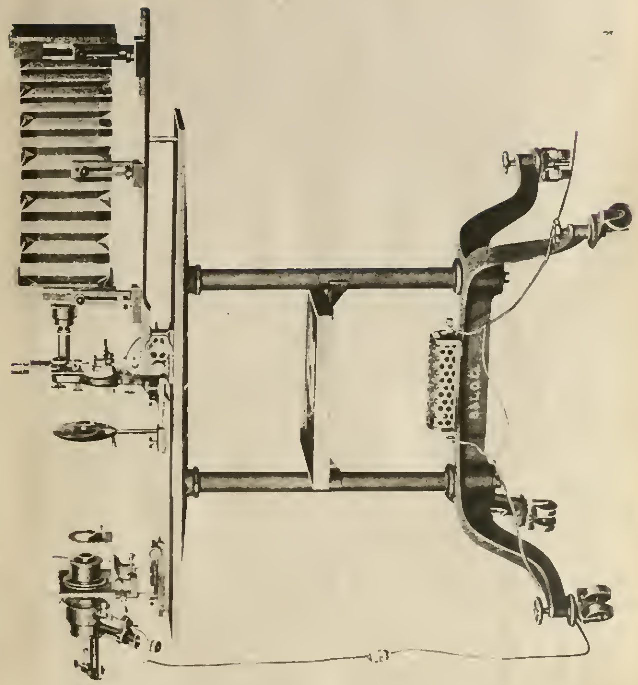
MICROSCOPIC ANALYSIS

The microscopic pictures which follow were made with the photomicrographic apparatus shown on page 182. A detail of the microscope is given in Fig. 23, page 183. No light filters were used as the cement surfaces were only partly and very imperfectly reflecting.

Standard Orthonon plates were used, at an exposure of three seconds with a number ten aperature. It was found that shutting down the aperature at the condenser lens provided a greater degree of detail than was otherwise obtainable.

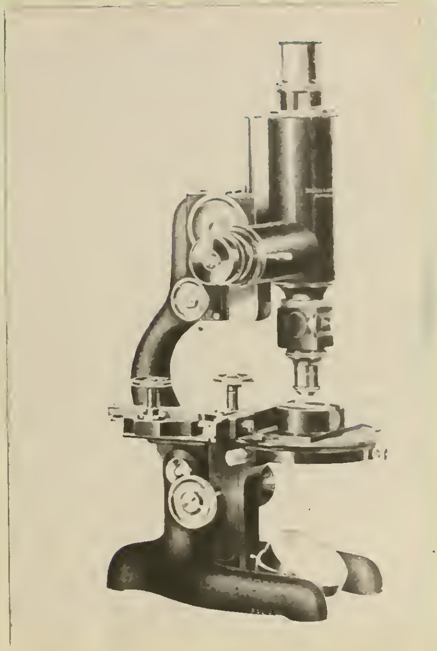
ALL MAGNIFICATIONS ARE AT TWENTY DIAMETERS. By taking larger magnifications it was found that the pictures showed an insufficiency of detail.

Before being photographed the specimen of mortar was first ground down to a smooth surface. It was then etched by being submerged in a one percent hydrochloric acid solution for a half hour. After being taken from the acid bath the specimen was rinsed to get rid of the surplus acid and after drying was polished on a piece of coarse lintless cloth.



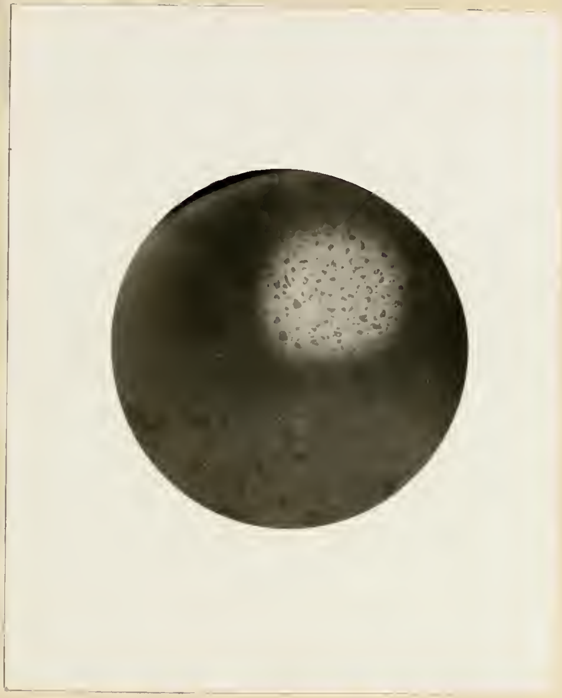
PHOTOMICROGRAPHIC APPARATUS

Fig. 22.



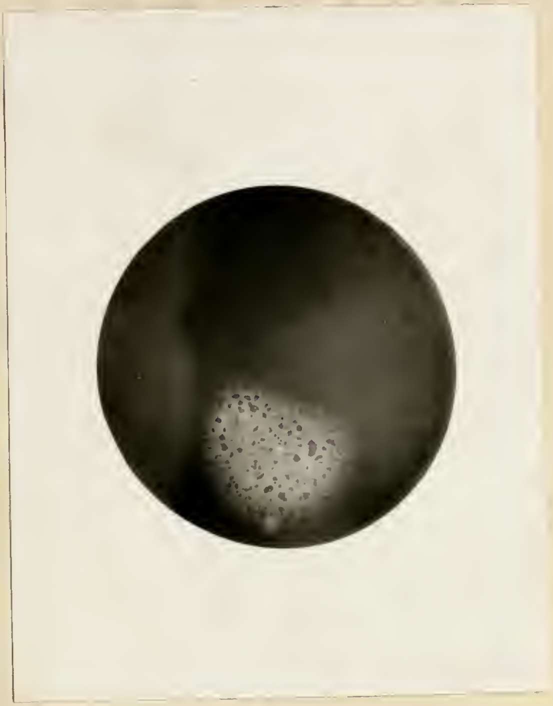
MICROSCOPE

Fig. 23.



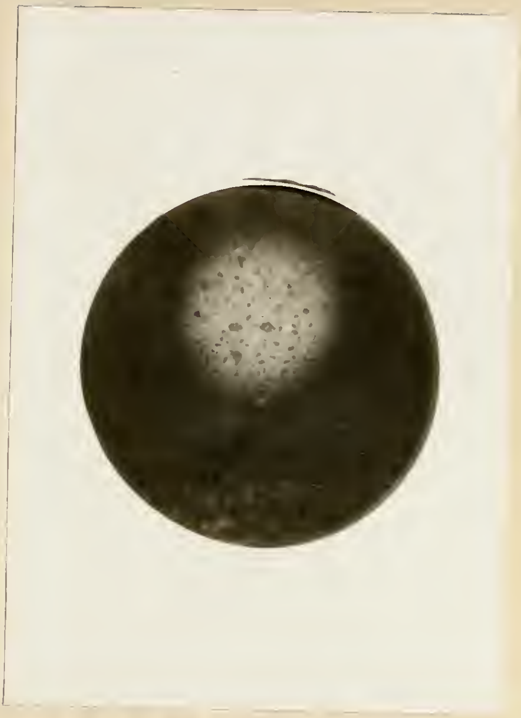
NEAT CEMENT 80% NORMAL CONSISTENCY.

MAGNIFIED 20 DIAMETERS.



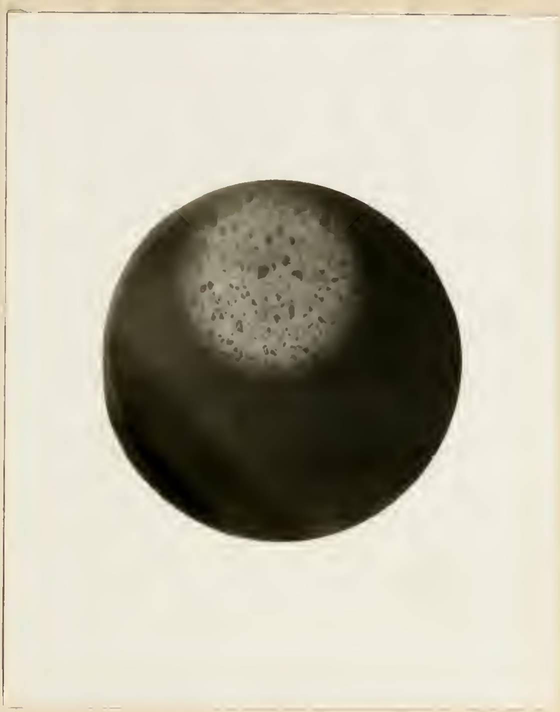
NEAT CEMENT 90% NORMAL CONSISTENCY.

MAGNIFIED 20 DIAMETERS.



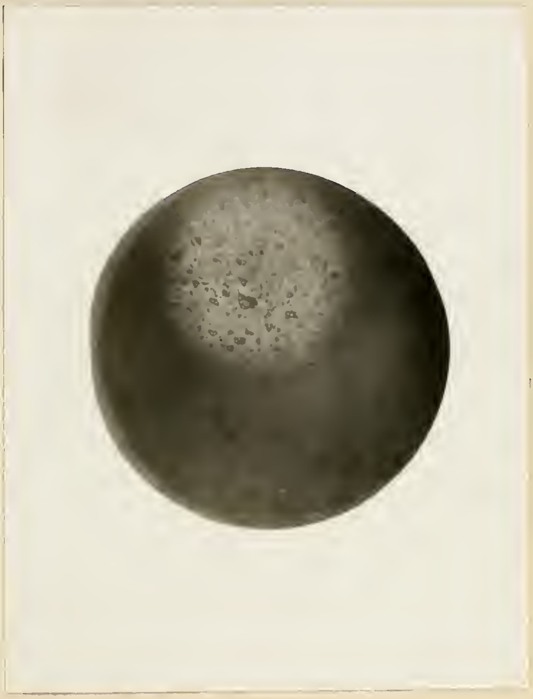
NEAT CEMENT 100% NORMAL CONSISTENCY.

MAGNIFIED 20 DIAMETERS.



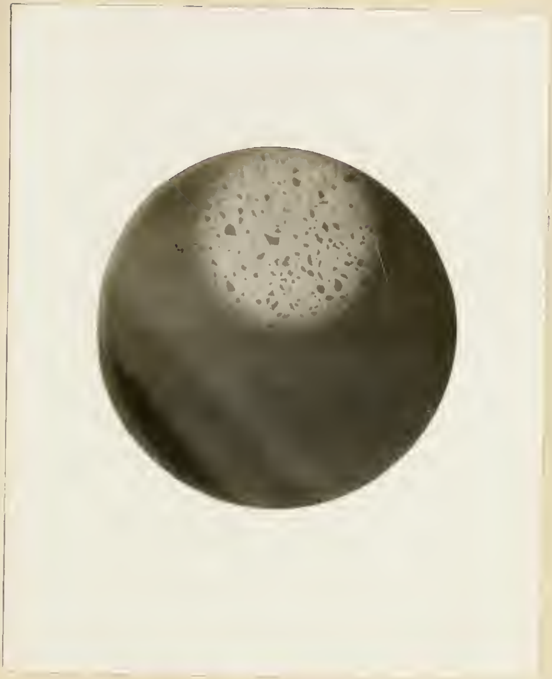
NEAT CEMENT 110% NORMAL CONSISTENCY.

MAGNIFIED 20 DIAMETERS.



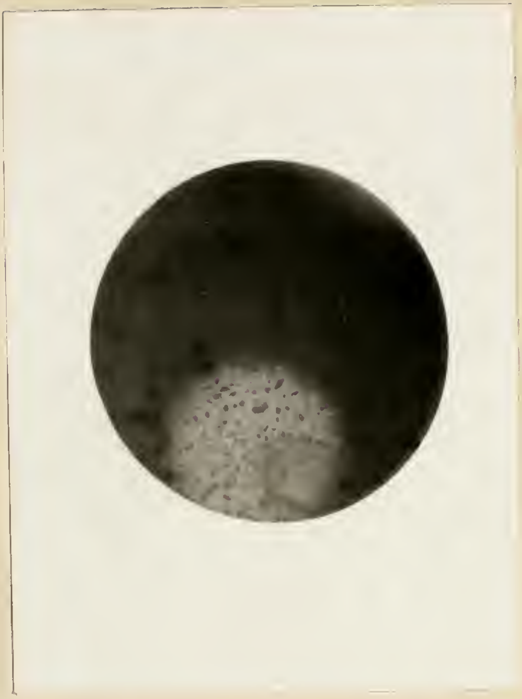
NEAT CEMENT 120% NORMAL CONSISTENCY.

MAGNIFIED 20 DIAMETERS.



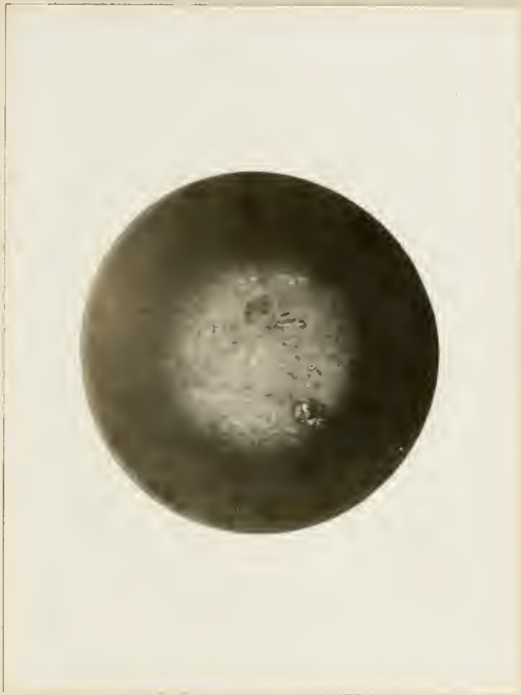
NEAT CEMENT 130% NORMAL CONSISTENCY.

MAGNIFIED 20 DIAMETERS.



NEAT CEMENT 140% NORMAL CONSISTENCY.

MAGNIFIED 20 DIAMETERS.

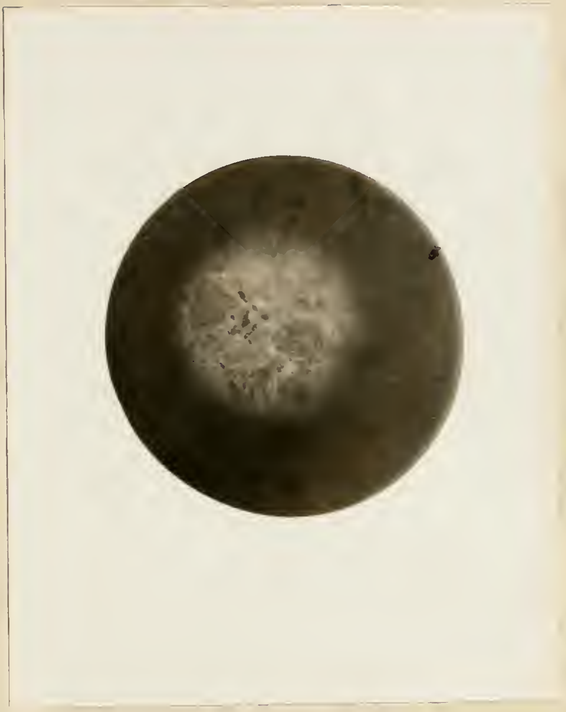


1 - 3 MORTAR 80% NORMAL CONSISTENCY.

MAGNIFIED 20 DIAMETERS.

1 - 3 MORTAR 90% NORMAL CONSISTENCY.

MAGNIFIED 20 DIAMETERS.

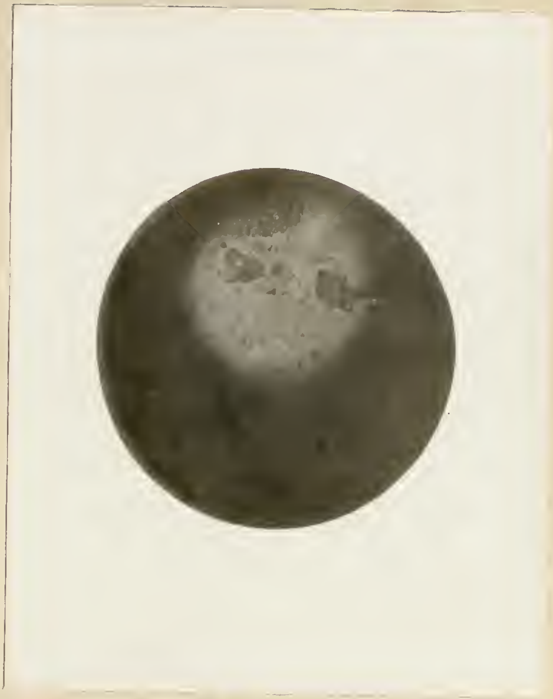


1 - 3 MORTAR 100% NORMAL CONSISTENCY.

MAGNIFIED 20 DIAMETERS.

1 - 3 MORTAR 110% NORMAL CONSISTENCY.

MAGNIFIED 20 DIAMETERS.



1 - 3 MORTAR 120% NORMAL CONSISTENCY.

MAGNIFIED 20 DIAMETERS.

1 - 3 MORTAR 130% NORMAL CONSISTENCY.

MAGNIFIED 20 DIAMETERS.

The chapter on microscopic analysis is almost self-explanitory and requires very little additional discussion. The fact brought out by the pictures included herein is that referred to in the chapter on preliminary discussion; that with an increase of the amount of mixing water the water voids in the mortar are increased in size.

The mortar mixed at 80% normal consistency, while it has the smallest voids, is weak because the reaction between the water and cement was not completed.

On page 190, where is shown neat cement at 140% normal consistency, it is seen that at very wet mixes, excessively large voids begin to appear.

In the pictures of 1 - 3 mortar, it is interesting to note that the voids occur very close to the aggregate.

CHAPTER VII

CONCLUSIONS

A resume of the tables of laboratory data gives the following figures:

	Number made.	Number Rej.	% Rej.
Briquettes	420	30	7.1
2" x 4" Cylinders	336	29	8.6
3" x 6" Cylinders	84	13	15.5

It would appear that the results for the larger cylinders were the least consistent but it must be remembered that for each large cylinder tested, four small cylinders were tested. the greater percentage of rejection of the larger cylinders was probably due to the fact that the average of a batch was swayed by a preponderance of the smaller cylinders.

The 3" x 6" cylinders, taken by themselves, indicate the trend of the experiments as well as do the smaller cylinders. It was for this reason that they were included when figuring the average unit strengths.

STRENGTH-CONSISTENCY CURVES, PRIMARY.

The STRENGTH-CONSISTENCY curves, for both compression and tension, pages 124 to 129, indicate that the least amount of variation in strength occurs in the mixes containing the larger amounts of sand. Appearances would tend to show that this was caused by change in percentage of normal consistency.

It must be borne in mind, however, that the amounts of mixing water used in obtaining similar normal consistencies in the various mortars were obtained by approximate methods and it may be due to the fact that the amounts of water used were somewhat incorrect that such a condition becomes apparent.

In such experiments as these, it is not possible to make definite statements of facts depending upon the relative consistencies of the different mortars. The conclusions must be limited to facts hinging upon the different percentages of normal consistency and upon the variations due to age in a single mortar.

Such points where intersections of primary

curves occur such as on pages 125 and 128, may be due to errors in moulding or testing and are not to be taken as a true indication of results as may be readily proved by a glance at the average curves.

STRENGTH-CONSISTENCY CURVES, AVERAGE.

In the average curves, any error due to the incorrect relative consistencies of the different mortars is overcome as each average curve contains all primary curves for all mortars of the same age.

On practically all average curves it is shown that a supply of mixing water below that amount required for normal consistency produces a mortar which is far weaker than one mixed with a greatly excessive amount of water. This is undoubtedly due to the fact stsated on page 3, viz, that the chemical reaction of the cement and water was not completed due to an insufficient supply of water. More of this will be said later.

The average curves on pages 131, 133, and 135, show the following:

Age in days.	Percent of normal for maximum strength.
7	90
28	100
90	120

The average curves on pages 137, 139, and 141, for tension, show the following:

Age in days.

Age in days.	Percent of normal for maximum strength.
7	100
28	110
90	110

From the above it is to be inferred that greater strengths at later ages are to be obtained by a slight excess of water. A large excess, however results in a weaker mortar. This is true for both compression and tension.

STRENGTH-CONSISTENCY CURVES, GENERAL.

STRENGTH-CONSISTENCY CURVES, GENERAL.

The following is obtained from Curve 18, page 144:

Min. compressive strength = 2100 Lbs./sq. in., and occurs at 80% normal consistency.

Max. compressive strength = 3410 Lbs./sq. in., and occurs at 100% normal consistency.

Strength at 140% normal consistency = 2680 Lbs./sq. in.

The following is obtained from Curve 19, page 146:

Min. tensile strength = 270 Lbs./sq. in., and occurs at 80% normal consistency.

Max. tensile strength = 400 Lbs./sq. in. and occurs at 100% normal consistency.

Strength at 140% normal consistency = 300 Lbs./sq. in.

From the above, it is seen that in compression, a percentage of normal consistency 20% less

than that percentage of normal consistency which produces the maximum strength results in a reduction of strength of 1310 Lbs./sq. in., or 38% less than the maximum, while a mortar containing 40% greater normal consistency than that required for maximum strength suffers a loss of only 730 Lbs./ sq. in. or about 21% less than the maximum strength.

In tension, the strength resulting from a mix 20% of normal consistency less than that required for maximum strength is 130 Lbs./sq. in., or about 33% less than the maximum, while that given by a mix 40% of normal consistency greater than that required for maximum strength shows a lossof 100 Lbs. /sq. in., or 25%.

It is seen, therefore, that an insufficient supply of mixing water produces a mortar very much weaker than that in which a considerably larger amount of water has been used.

This fact emphasizes the importance of p proper mixing. If mixing is not done properly and thoroughly, some of the cement will not be brought into contact withbsufficient water and the result

will be the same as indicated herein.

the percentage of loss of strength due to the use of too much water and that due to the use of not enough water are similar for both tension and compression.

STRENGTH-AGE CURVES, PRIMARY.

The primary STRENGTH-AGE curves emphasize further the weakness of a mortar due to the use of too little water. In almost every case, for all ages and mortars, the 80% curve is lower than all the others. This is true for both tension and compression.

It is also shown that mortars containing the greater proportions of sand are less subject to variations in strength due to variations in the percentages of normal consistency. This fact is indicated by the wide range of mortars curves of the mortars which are rich in cement and the comparatively narrow range of the curves of mortars which contain a large proportion of sand. This is true for both compression and tension.

For example: the range of the STRENGTH-AGE curves of various consistencies fo compressive strengths of neat cement as shown on page 148, (Curve 20) is from 2890 to 4560 for seven days and from 4010 to 6570 for 90 days, while the range of the curves on page 151, (Curve 23) which are for compressive strengths of 1 - 3 mortars of various consistencies is from 600 to 870 for 7 days, and from 1040 to 2650 at 90 days.

In neat cement the range is 1670 for7 days, and 2560 for 90 days.

In 1 - 3 mortar the range is 270 for 7 days and 1610 for 90 days.

The range increases with age.

The primary STRENGTH-AGE curves also show that for a given mortar, a slightly wetter mix will result in an increased strength at a later age. This change may be assumed to occur near the age of 28 days as the curve intersections mostly occur near the 28 day ordinate. This is true for both compression and tension.

STRENGTH-AGE CURVES, AVERAGE.

Without exception, the average STRENGTH-

AGE curves show that the maximum gain in strength occurs between 28 and 90 days. It is therefore very unwise to subject mortar to loading or to wear before it has reached an age of from 60 to 90 days.

STRENGTH-AGE CURVES, GENERAL.

The following data is obtained from Curve 36, page 175.

Compressive strength at 7 days = 2070 Lbs./sq. in.
Compressive strength at 28 days = 2720 Lbs. / sq. in.
Compressive strength at 90 days - 4080 Lbs./sq. in.

The compressive strength at 7 days is 50.7% of the compressive strength at 90 days, and at 28 days it is 66.7%. The increase in strength from 7 to 28 days is but 16.0% while from 28 to 90 days it is 33.3%, or more than twice as much.

The following data is obtained from Curve 37, page 177.

Tensile strength at 7 days - 260 Lbs./sq. in.
Tensile strength at 28 days = 350 Lbs./sq. in.
Tensile strength at 90 days = 430 lbs./sq. in.

The tensile strength at 7 days is 60.5% of the tensile strength at 90 days, and at 28 days it is 81.4%. The increase in strength from 7 to 28 days is 20.9% and from 28 to 90 days it is 18.6%.

The proposition of gain in strength over a given period of time is subject to great variation as has been found in other experiments by the writer. This is probably due to the variation in chemical constiution of the different cements.

FINAL

The foregoing conclusions permit the writer to make the following statements:

1. THE MAXIMUM TENSILE AND COMPRESSIVE STRENGTHS OF A TYPICAL PORTLAND CEMENT MAY BE SAID TO OCCUR AT ABOUT 100% NORMAL CONSISTENCY? ALLOWING FOR A VARIATION OF APPROXIMATELY 5% EITHER WAY.

2. A MORTAR IN WHICH THE AMOUNT OF MIXING WATER USED HAS BEEN INSUFFICIENT (80%NORMAL CONSISTENCY) IS OF FAR LESS STRENGTH THAN A MORTAR IN WHICH THE AMOUNT OF MIXING WATER HAS BEEN EXCESSIVELY GREAT. (140 NORMAL CONSISTENCY.)

3. MORTARS CONTAINING LARGE PROPORTIONS OF SAND ARE LESS SUBJECT TO VARIATION IN STRENGTH DUE TO VARIATION OF PERCENTAGE OF MIXING WATER THAN ARE MORTARS CONTAINING SMALLER PROPORTIONS OF SAND.

4. THE VARIATIONS IN STRENGTH DUE TO THE VARIATION OF THE PERCENTAGE OF NORMAL CONSISTENCY ARE LEAST AT THE LOWER AGES.

5. THE GAIN IN STRENGTH FROM 7 TO 28 DAYS IS GRADUAL AS IS THE GAIN IN STRENGTH FROM 28 TO 90 DAYS.

6. COMPRESSIVE AND TENSILE STRENGTHS ARE SIMILARLY AFFECTED BY VARIATION IN PERCENTAGE OF MIXING WATER AND BY VARIATION IN AGE.

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